FATRAS —

A Novel Fast Track Simulation Engine for the ATLAS Experiment

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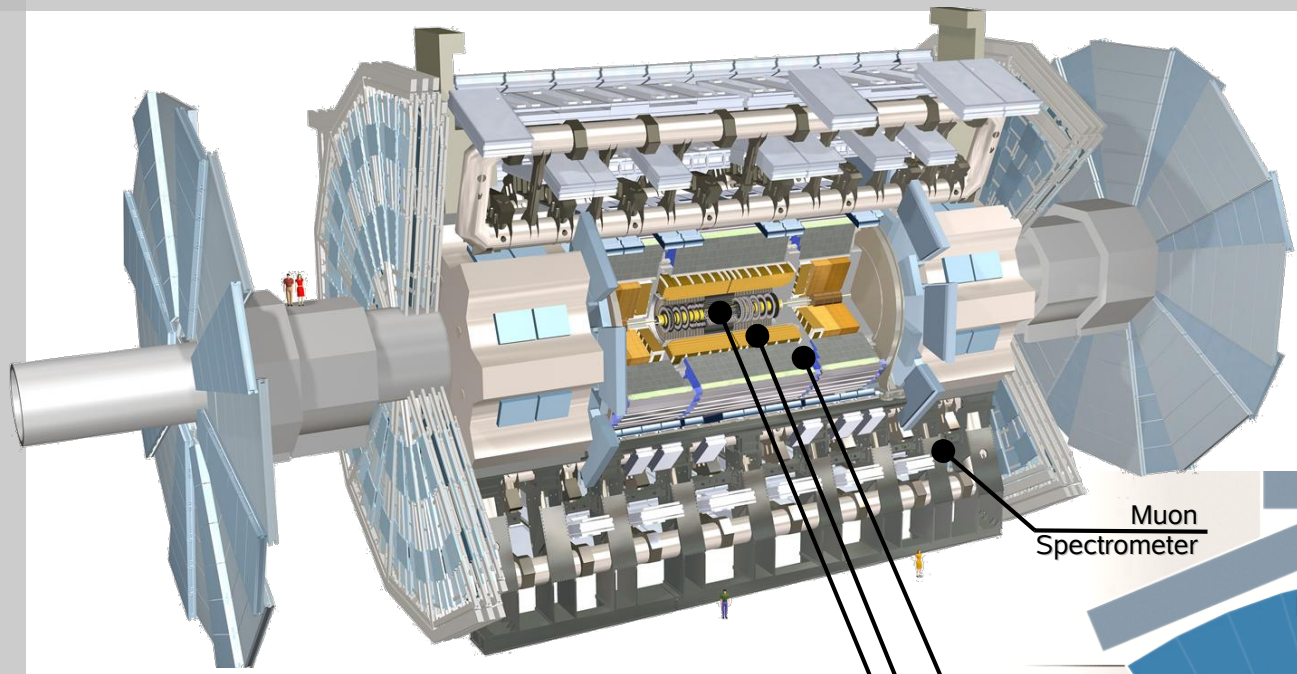
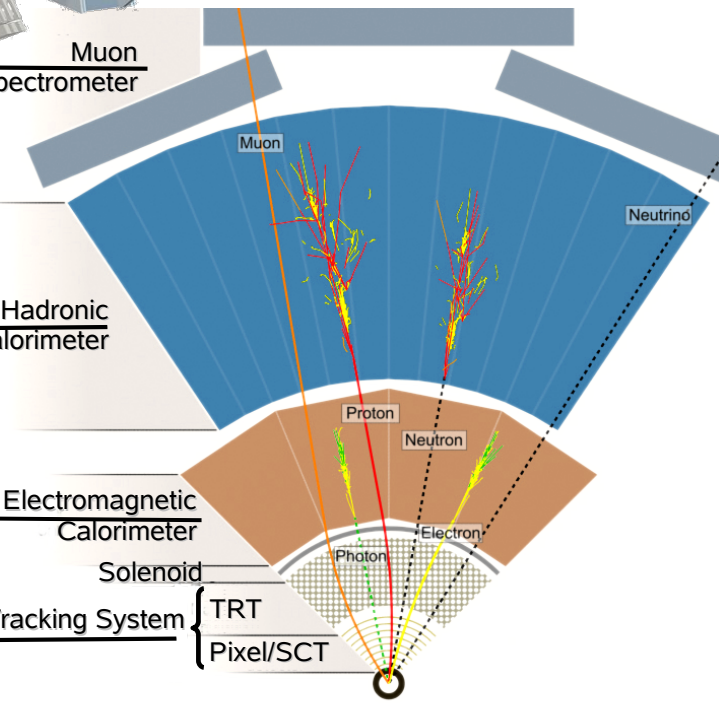
fatras

Outline

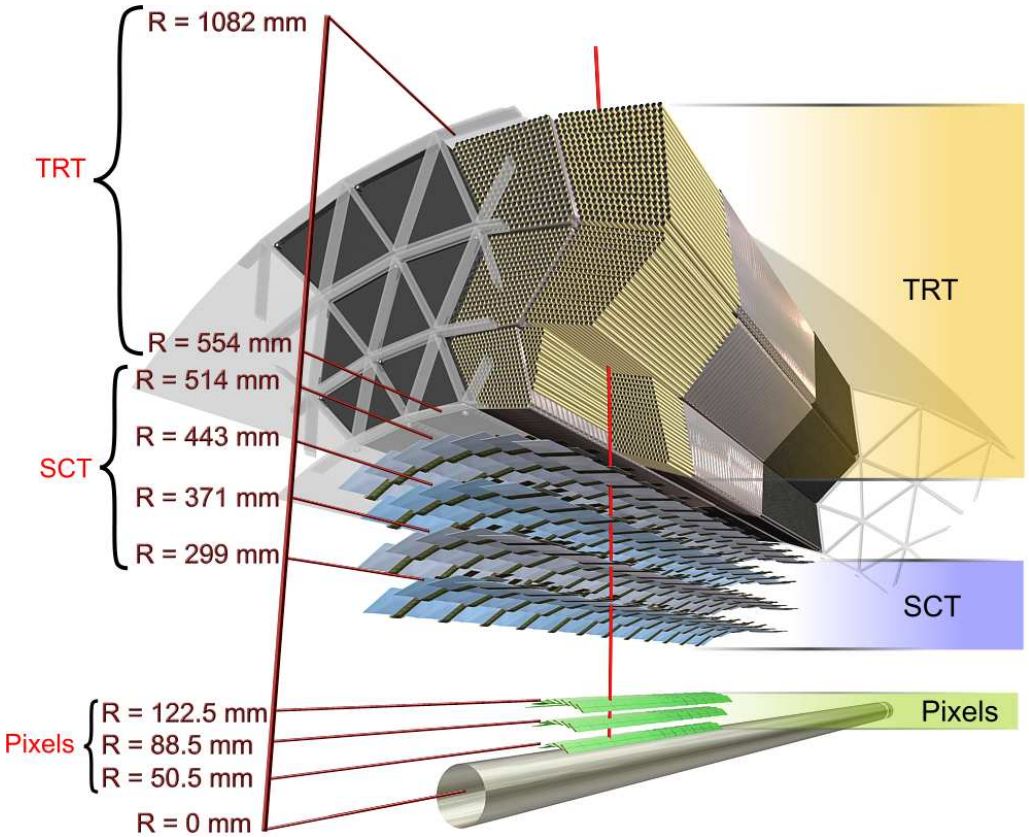
1. Introduction
   - The ATLAS detector
   - Fast detector simulations – Why?
2. Simulation strategies
   - Track simulation in FATRAS
   - Digitisation
   - Combined simulation: Tracking and calorimetry
   - Comparison to other simulation strategies
3. Performance
   - Comparison with full simulation
   - Comparison with collision data
   - Special use-cases and applications
4. Summary

The ATLAS detector





The ATLAS Inner Detector

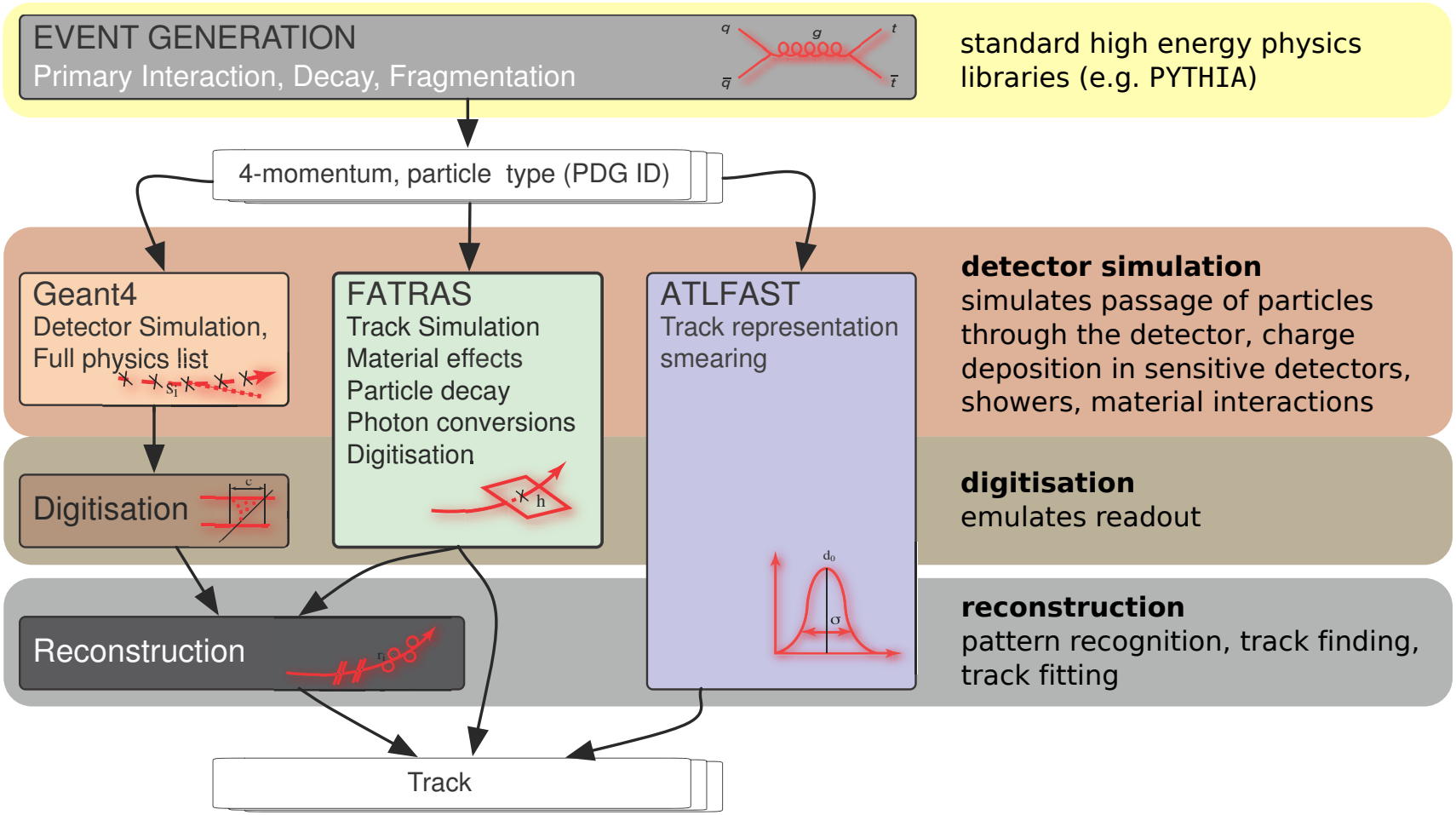


- TRT drift tubes
  - $\approx$ 300 000 straw tubes
  - 130 μm resolution ($R\phi$)
  - $Xe/CO_2/O_2$
  - about 30 measurements per track
- SCT silicon strips
  - $\approx$ 6 million Si strips
  - resolution: 17 μm ($R\phi$)/580 μm (Z)
  - 4 (double) measurements / track
- silicon Pixel
  - $\approx$ 80 million Si pixels
  - resolution: 10 μm ($R\phi$)/115 μm (Z)
  - 3 measurements / track
- 2 T solenoidal field

Why do we need fast detector simulations?

- Monte Carlo simulation of detector response is needed to compare theoretical predictions (by Monte Carlo event generators) to data
- Detailed simulation of particles penetrating the detector material is CPU-time consuming
  - Simulation of a single $t\bar{t}$ event in full Geant4 simulation takes about 30 kSI2Kminutes
- Fast simulation techniques can increase the amount of simulated events

Track simulation strategies

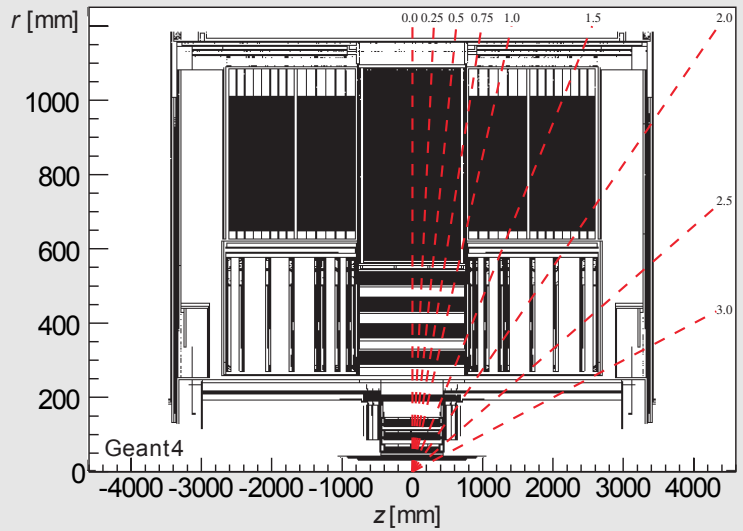


The simulation scheme of fatras

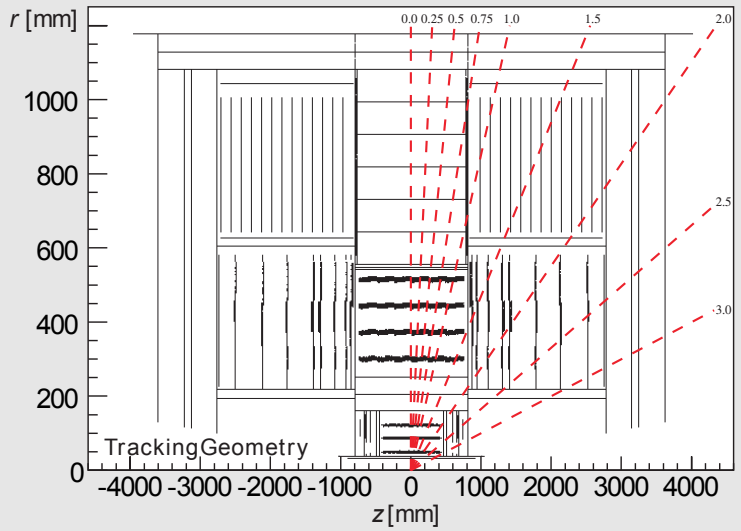
- fatras uses the component model of the ATLAS software
  - take extrapolation engine of the ATLAS track reconstruction
  - reconstruction modules, such as the estimation of energy loss, are replaced by Monte Carlo implementations
  - event data objects identical to full simulation or real data
- Where feasible, Geant 4 modules are used, such as particle decays
- Nearly all effects are estimated from first principles (Bethe-Bloch, etc.)
  - no parametrisations used, despite hadronic interactions

ATLAS Inner Detector Geometry

Geant 4



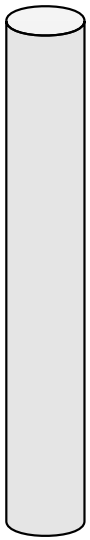
Tracking Geometry

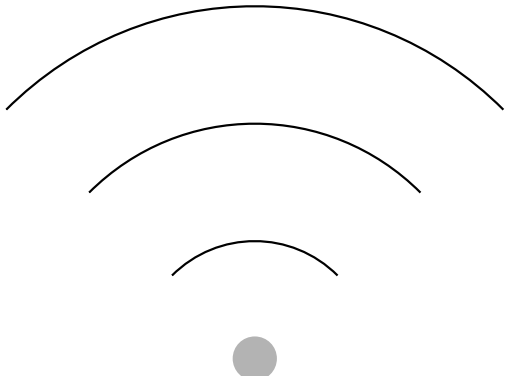


- Track reconstruction in ATLAS uses greatly simplified detector description
  - Sensitive elements identical to full Geant 4 description!
- fatras uses the same!

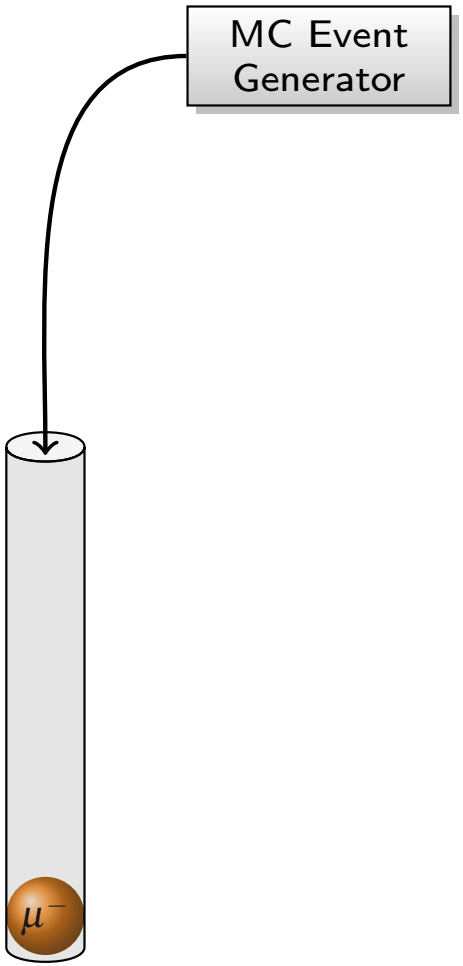
Track simulation in fatras

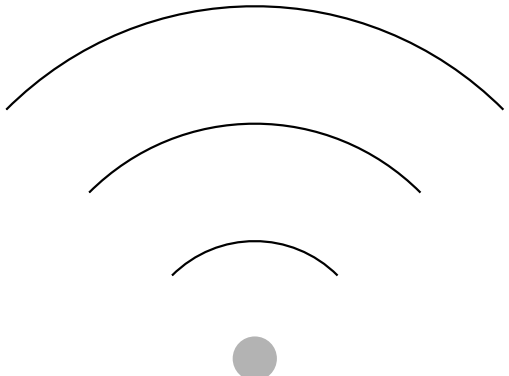
MC Event Generator





Track simulation in fatras





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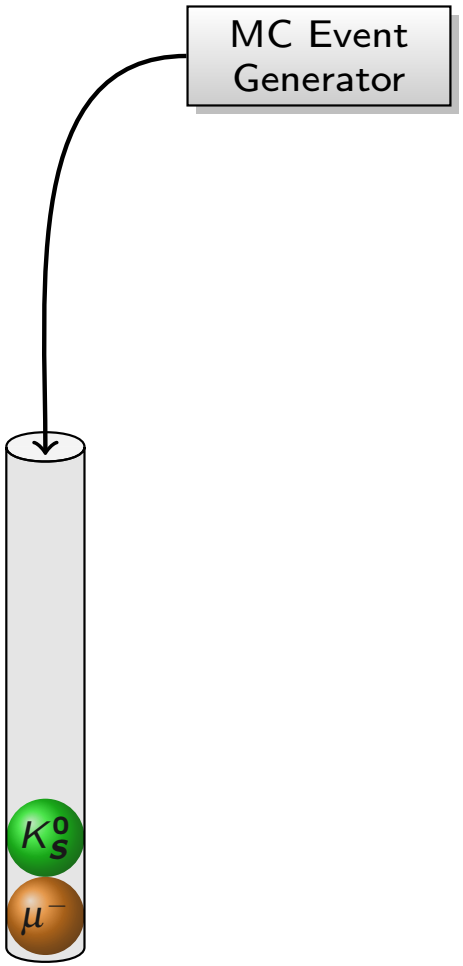

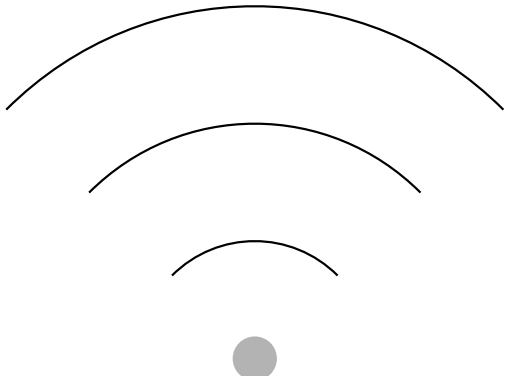

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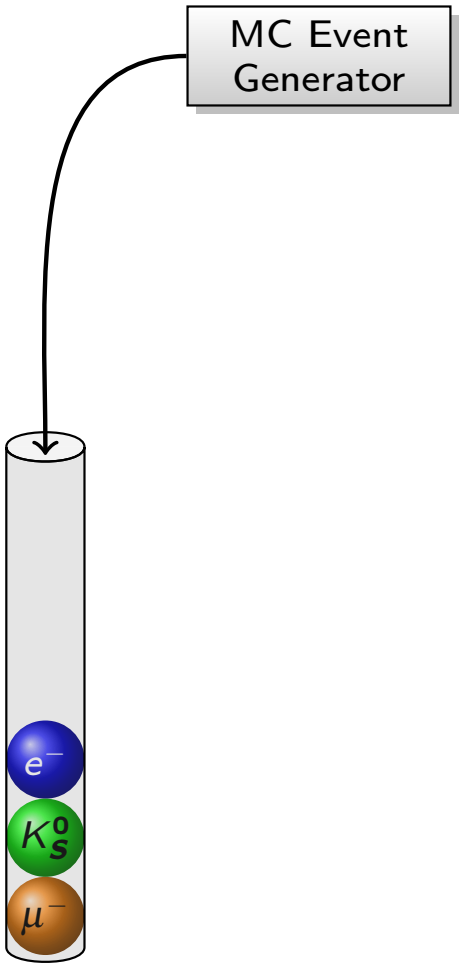

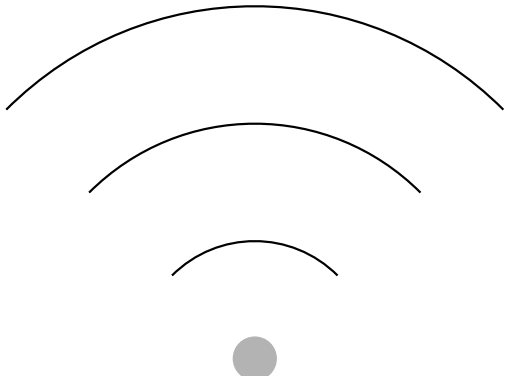

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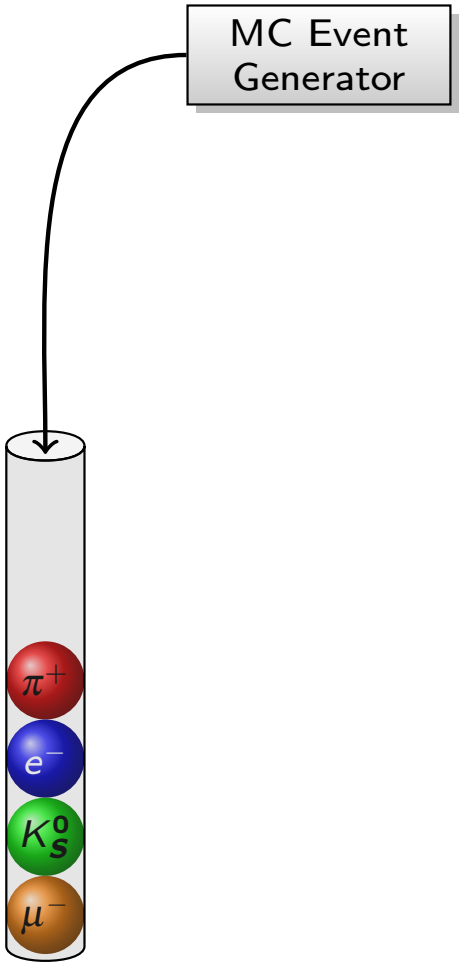
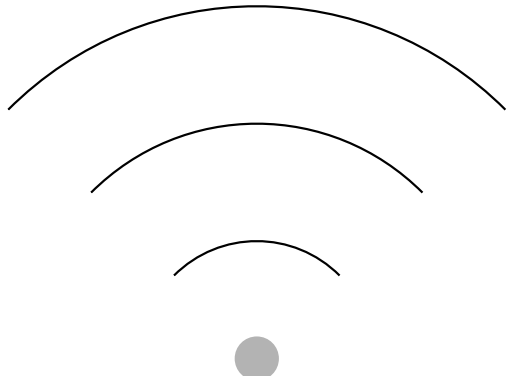
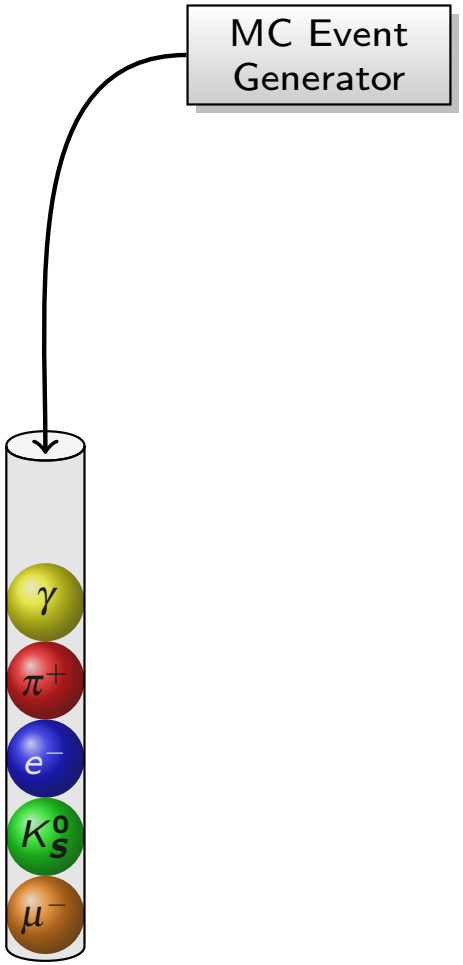
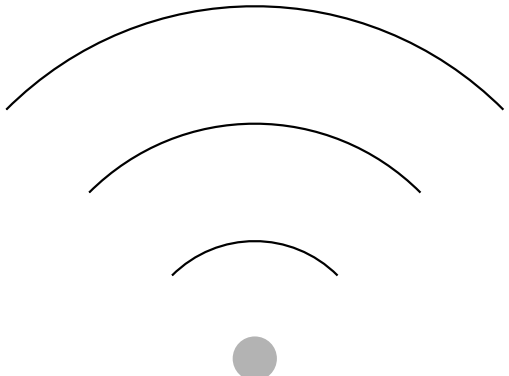




Track simulation in fatras





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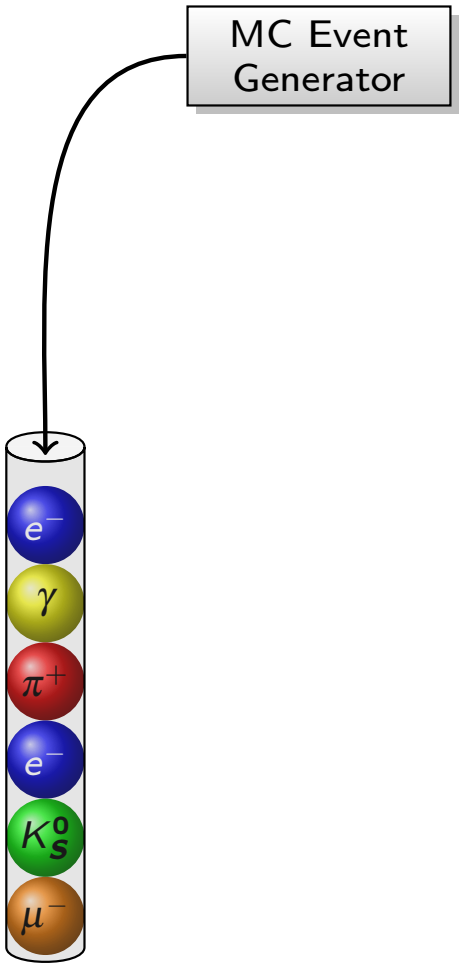

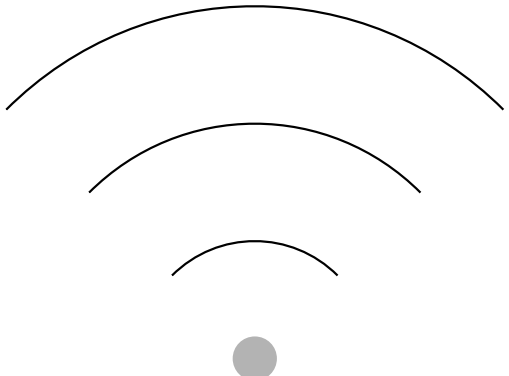

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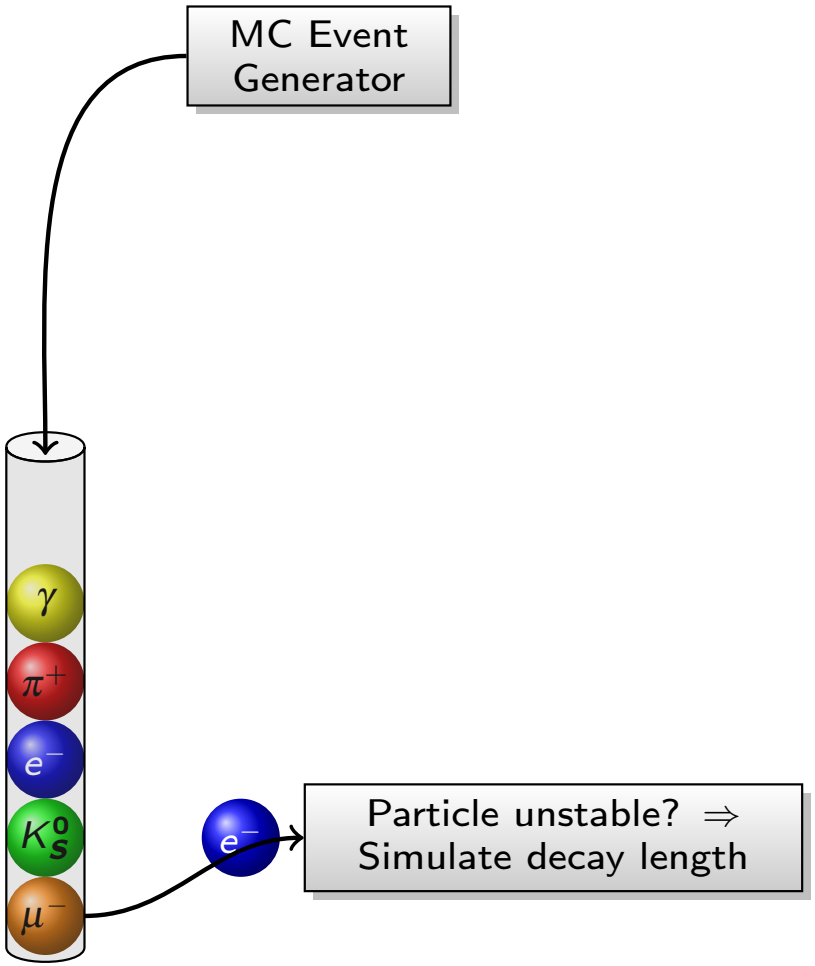

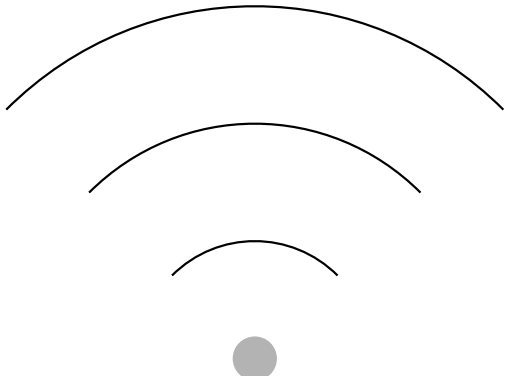

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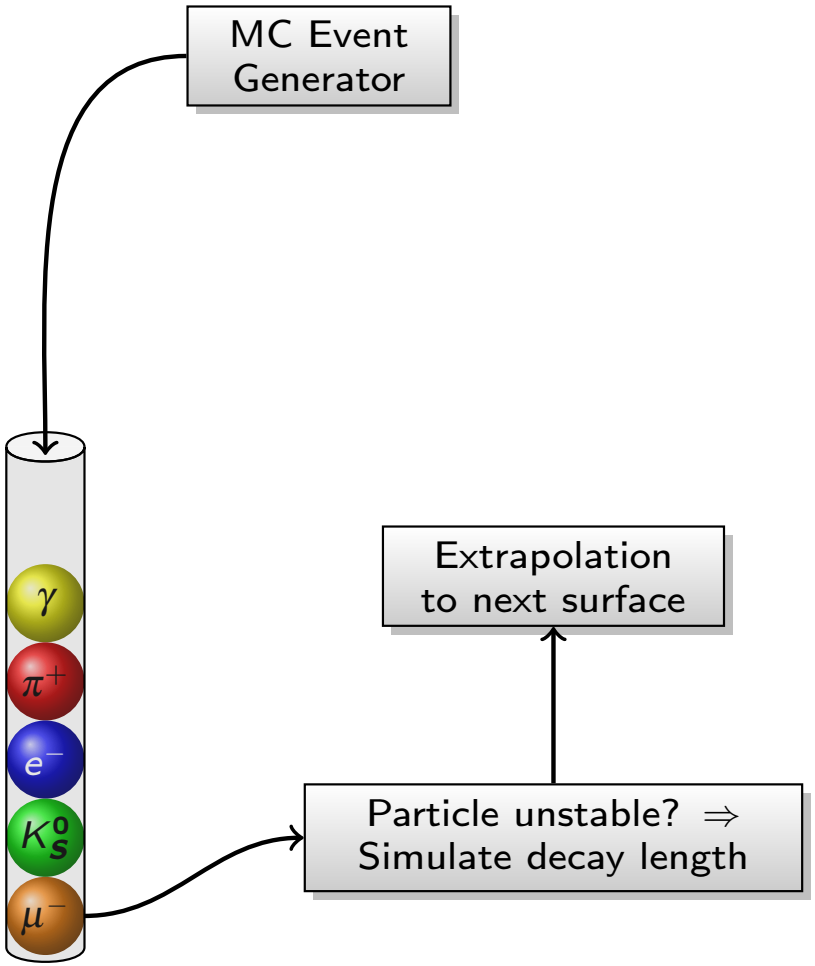

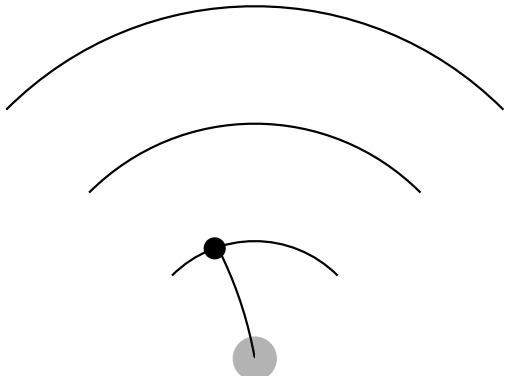

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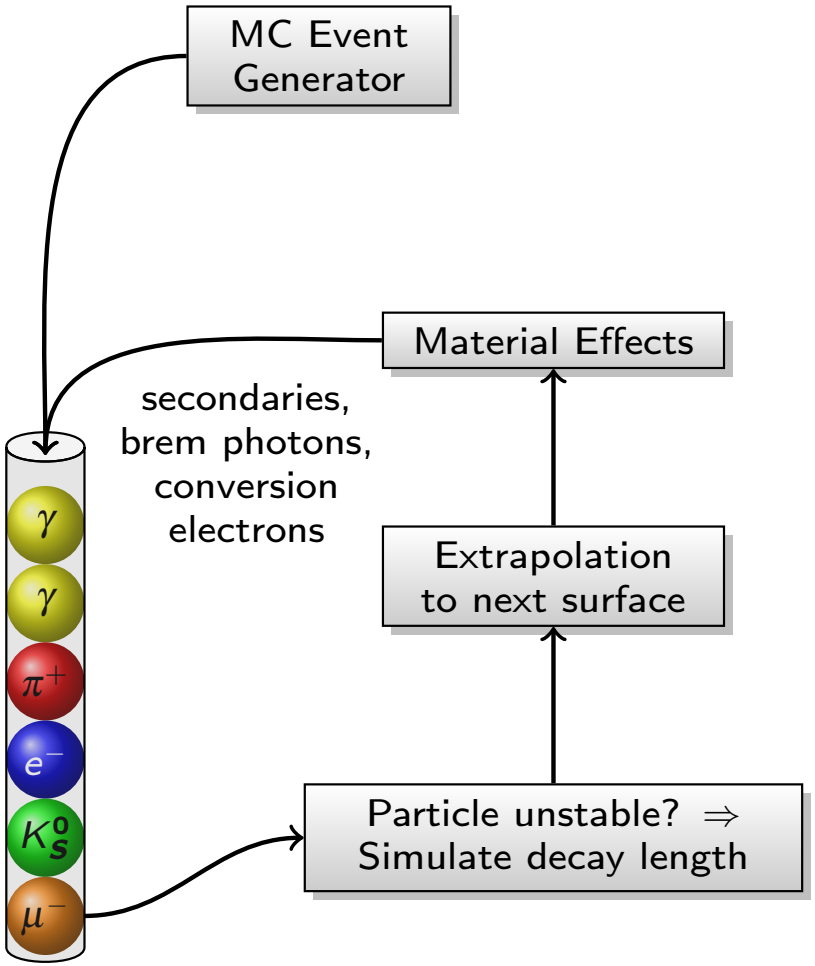

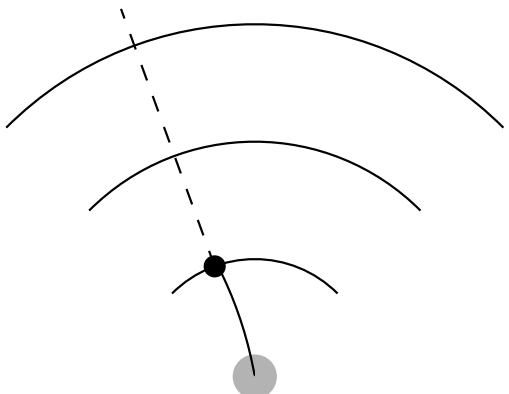

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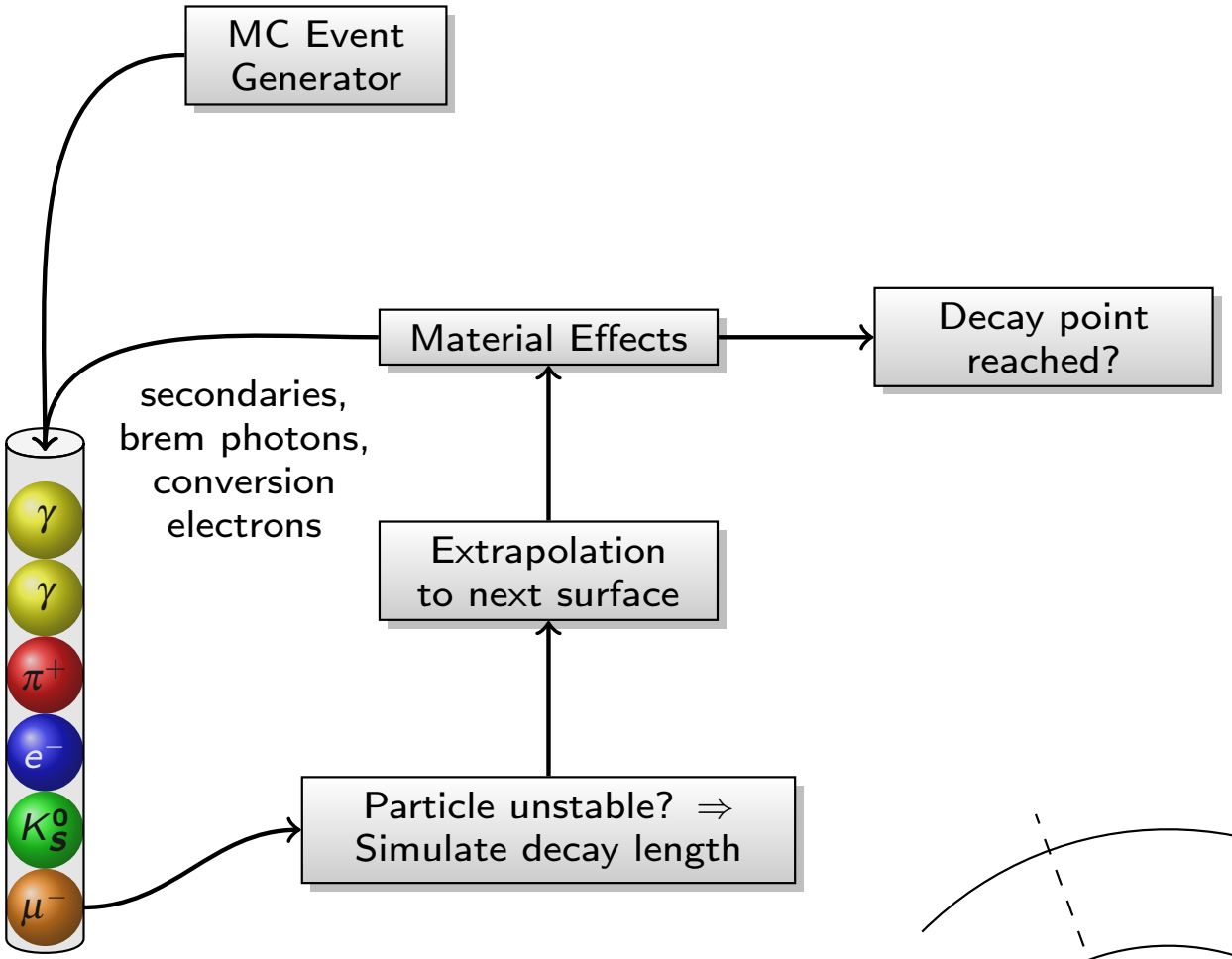

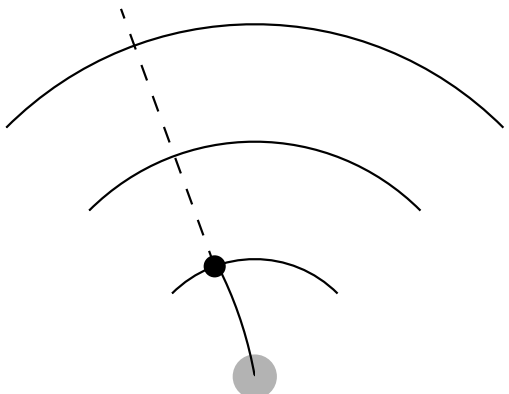

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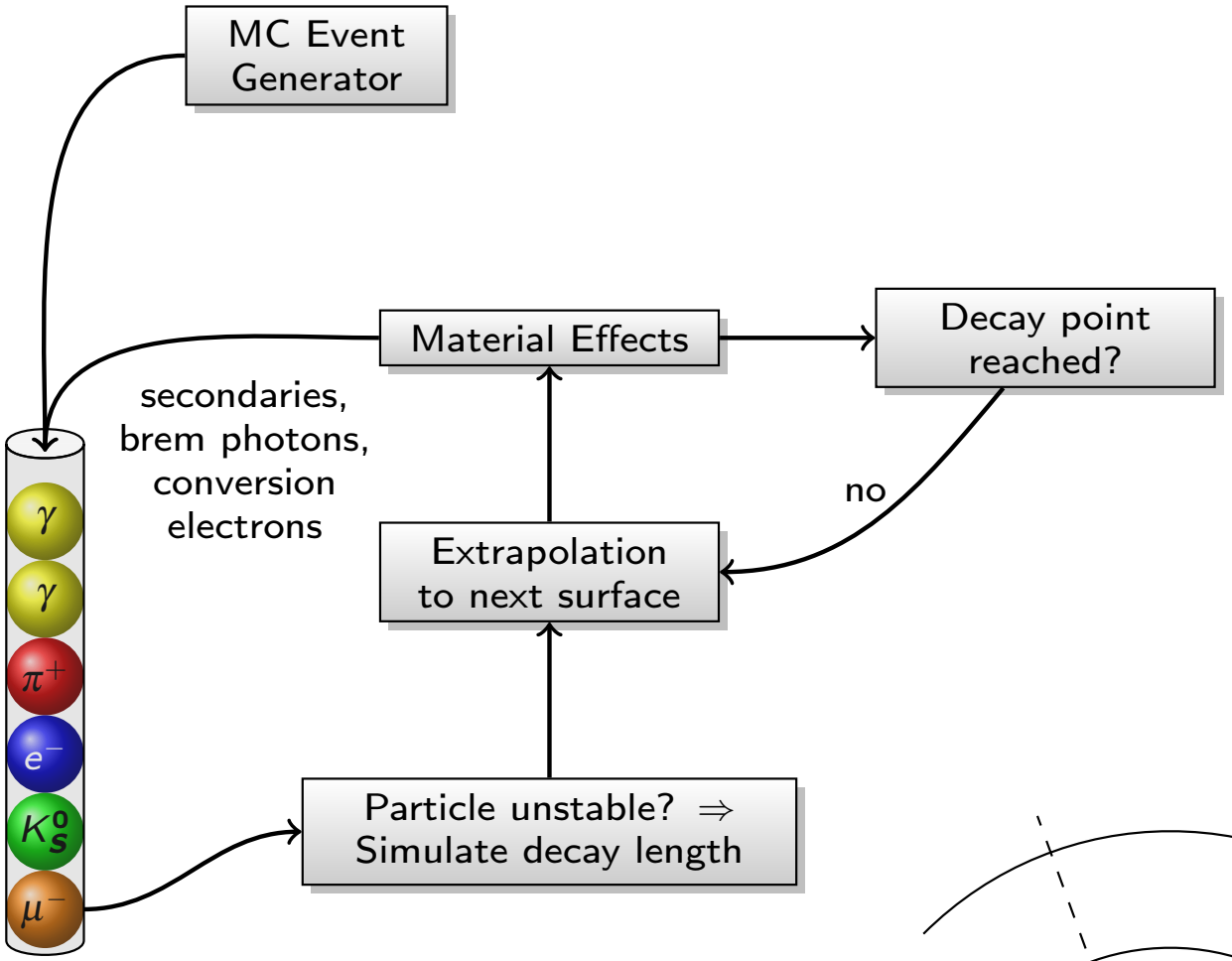

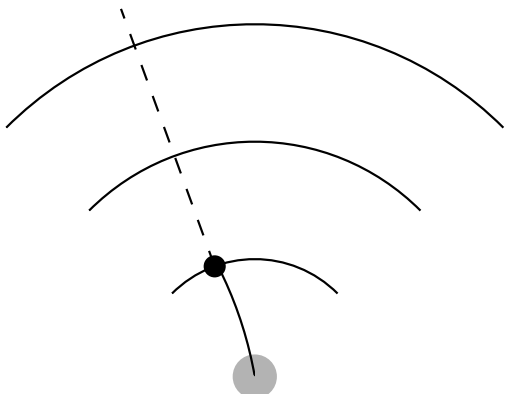

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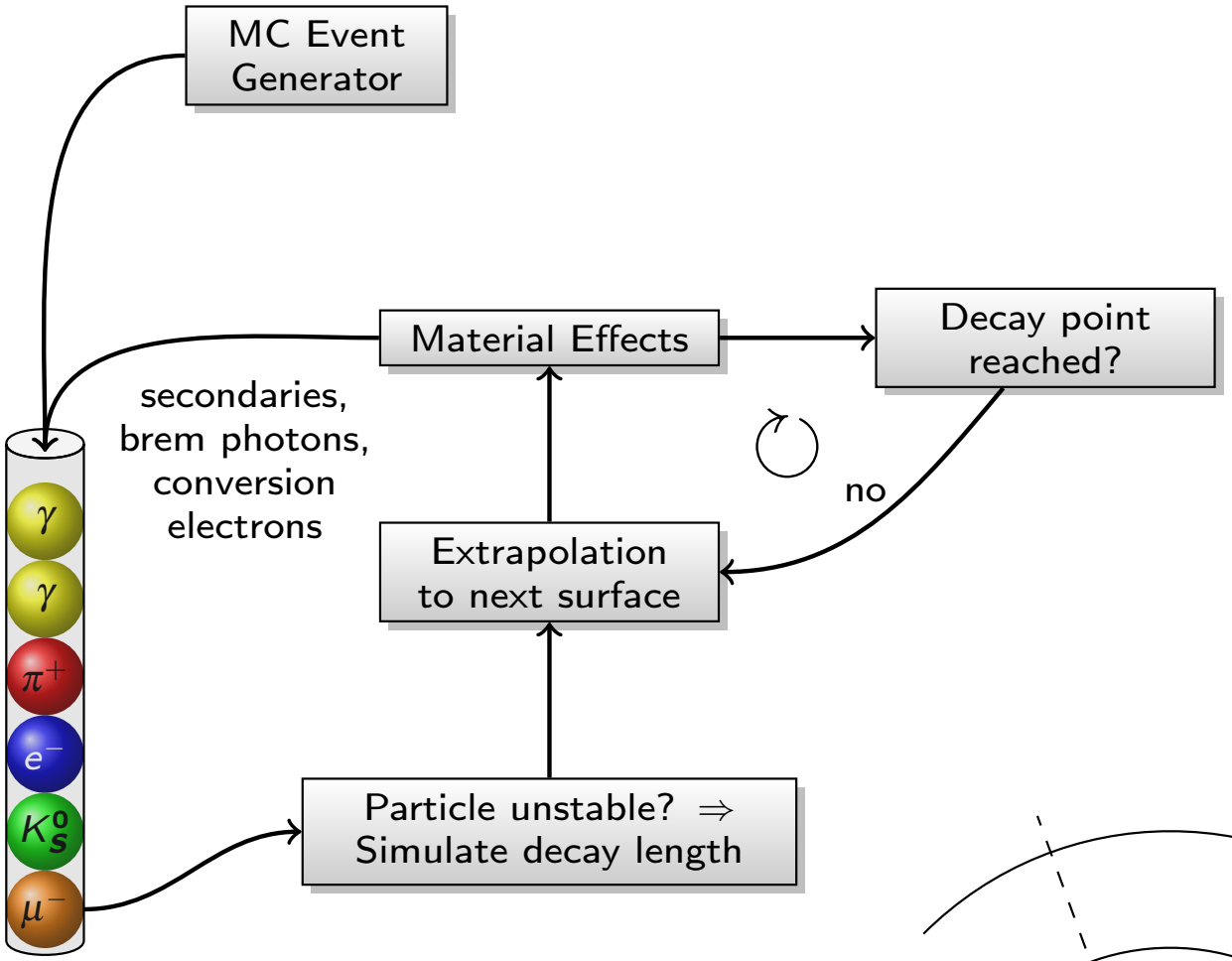

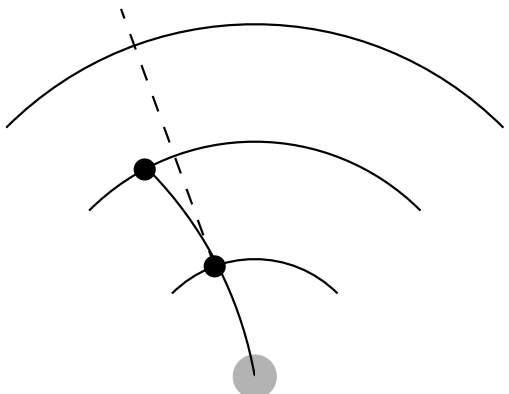

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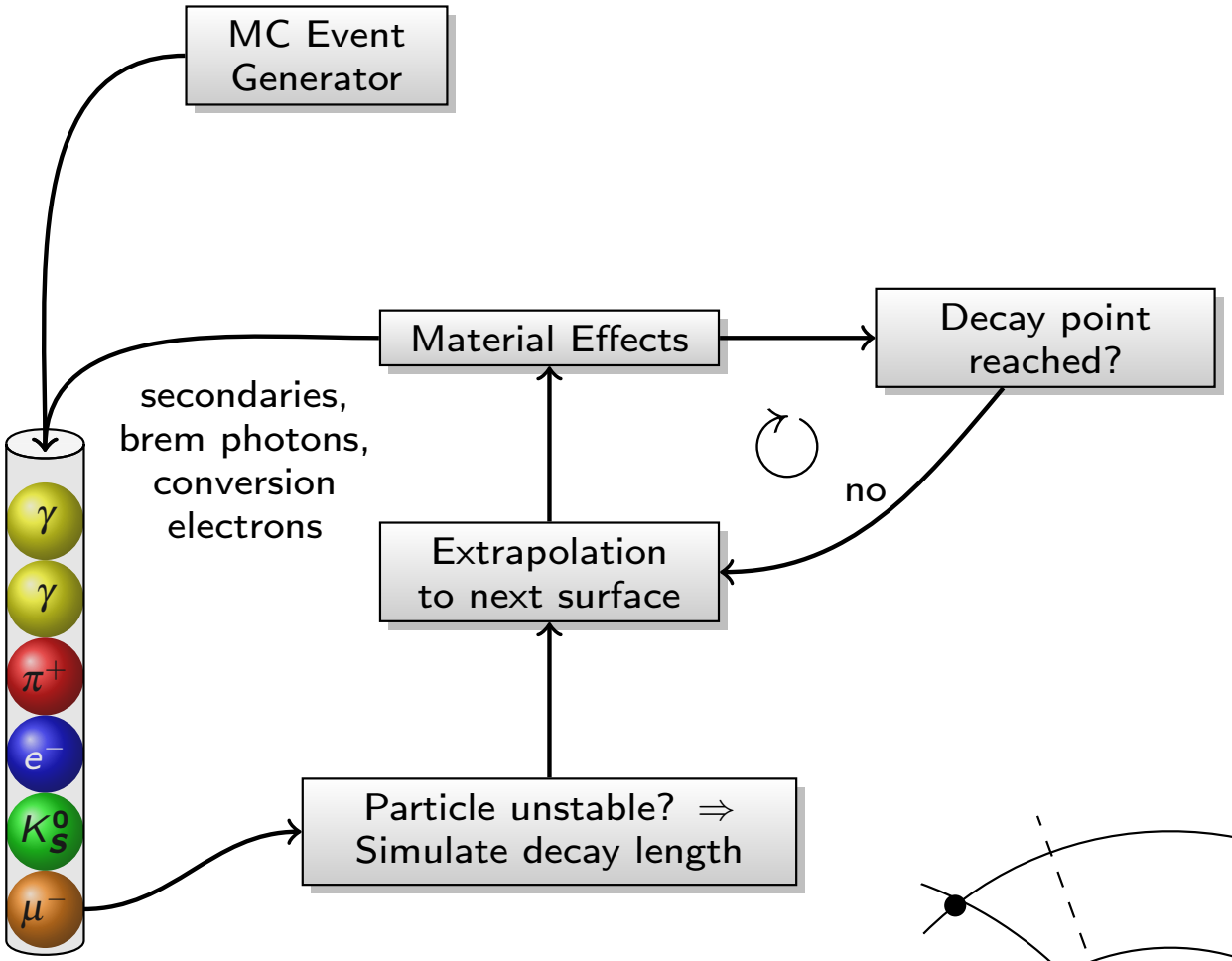

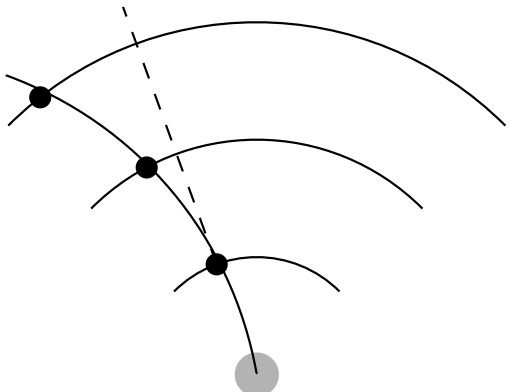

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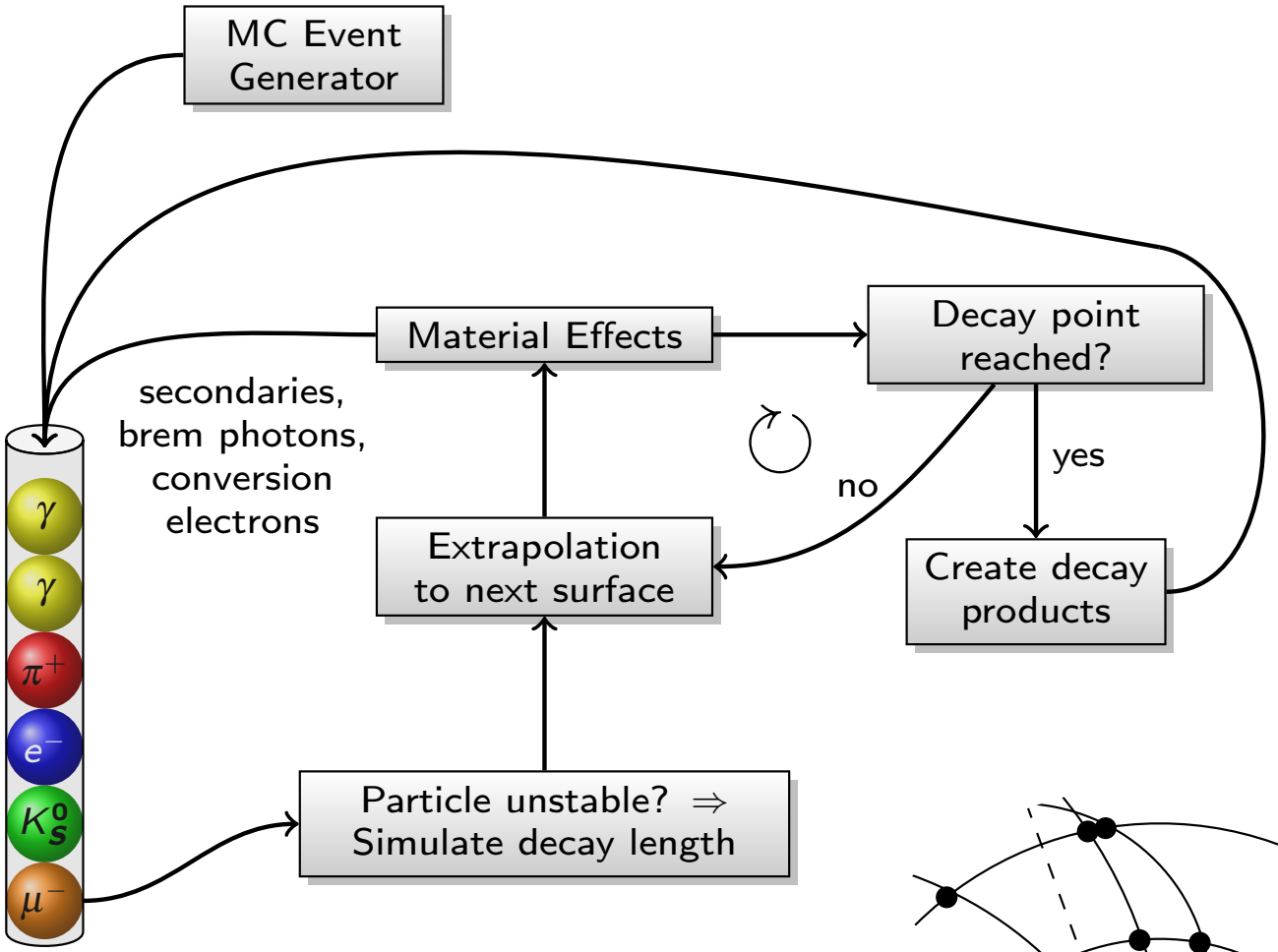
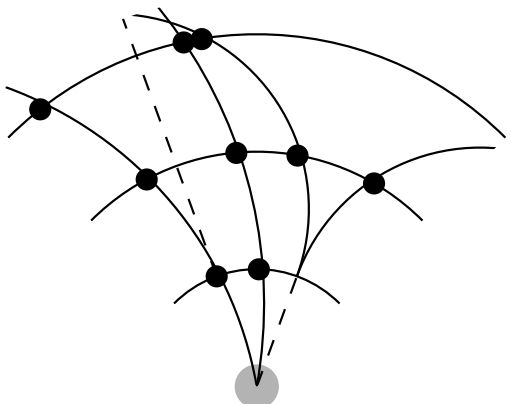
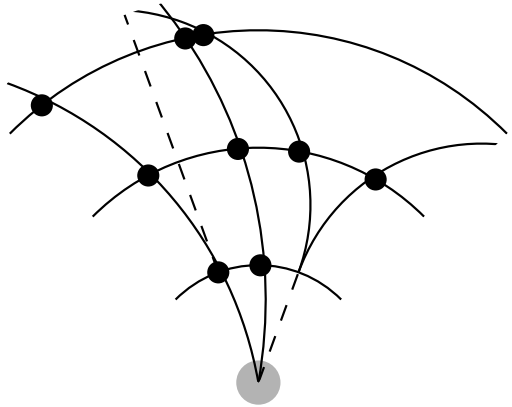




Track simulation in fatras

Postprocessing



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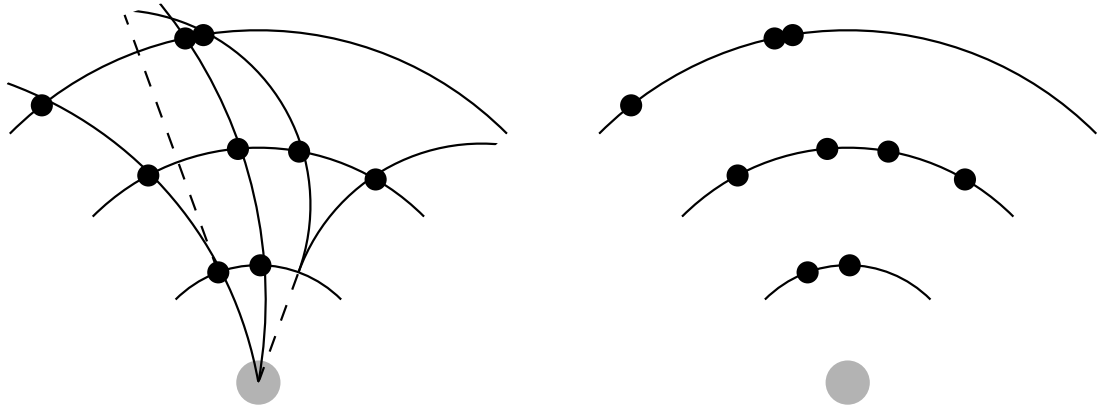
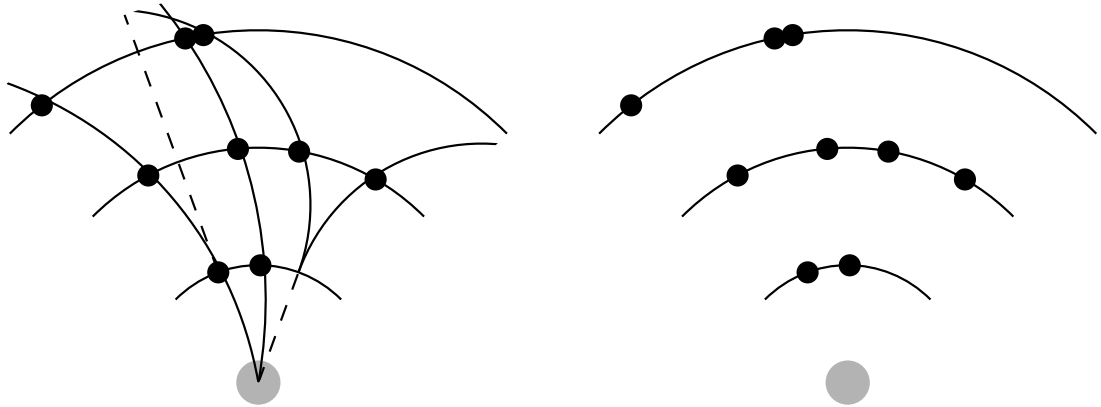


Extract measurements from simulated tracks

Track simulation in fatras

Postprocessing



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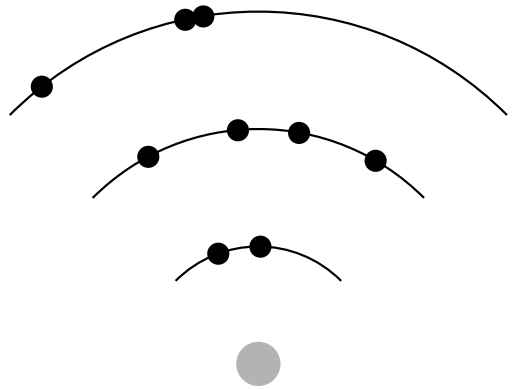

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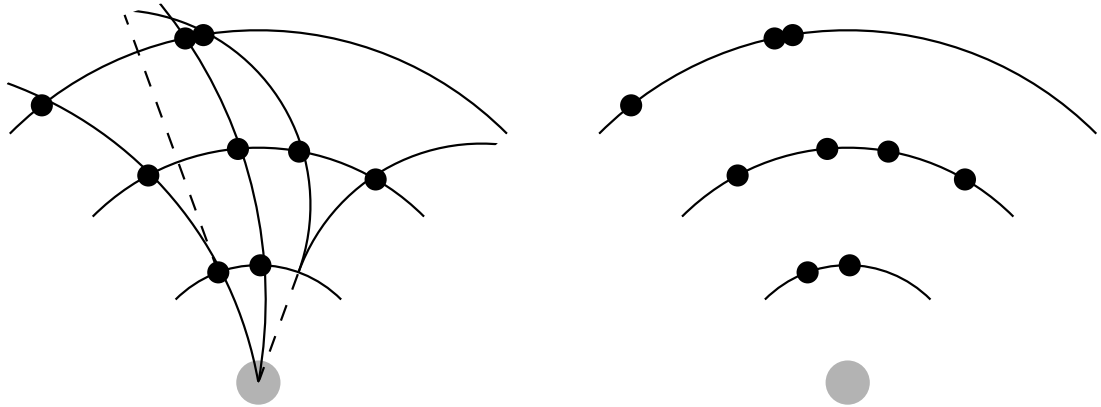

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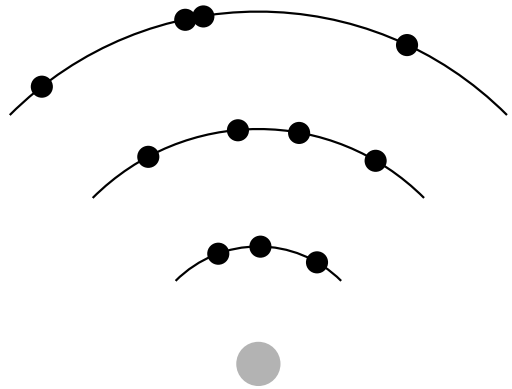
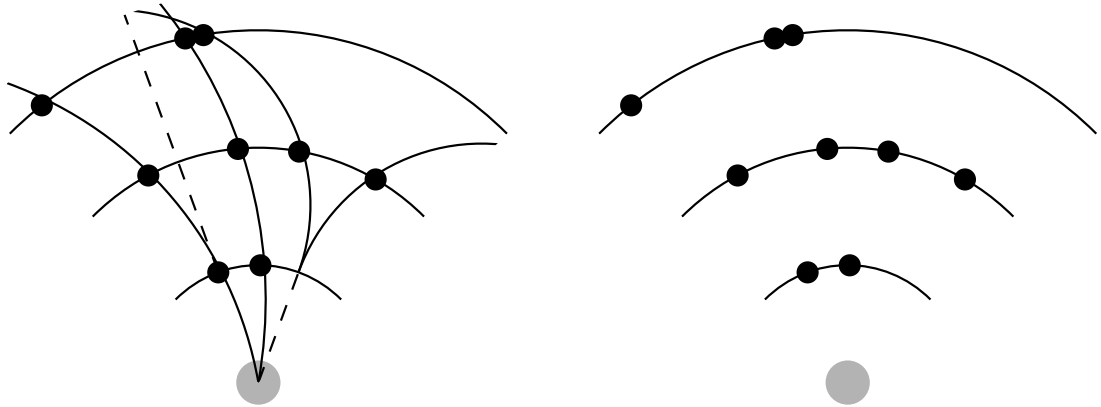
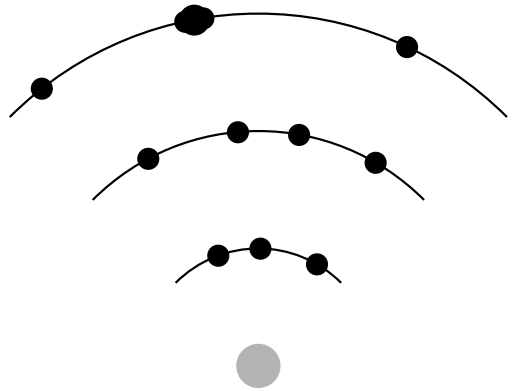


Add noise

Track simulation in fatras
Postprocessing



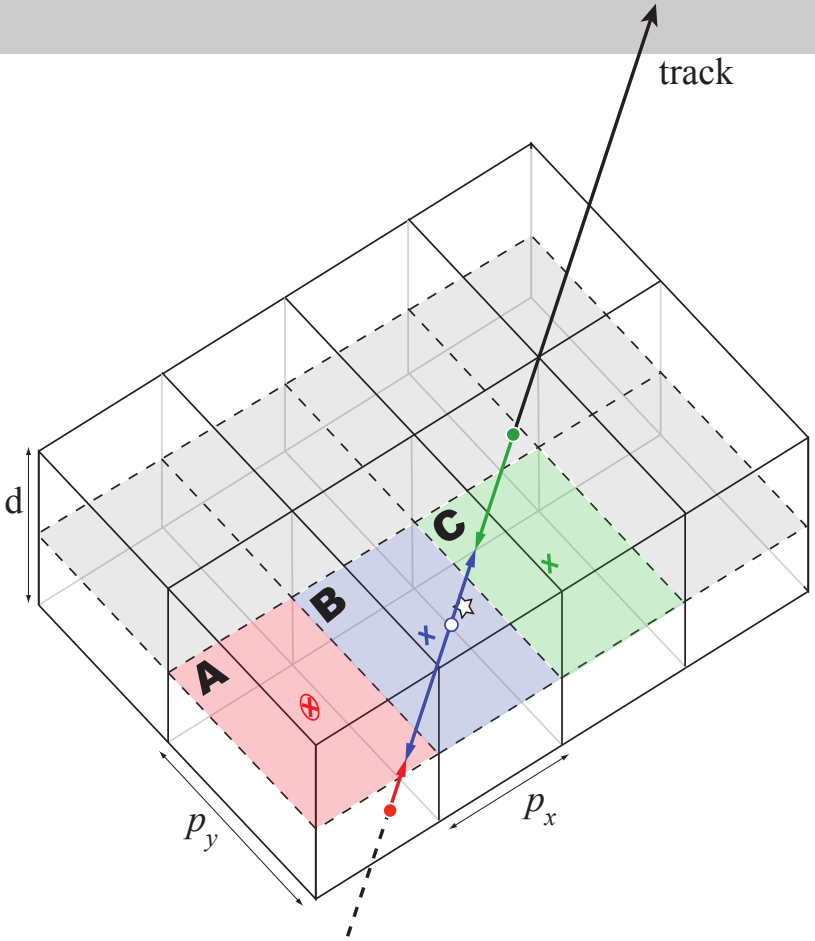
Extract measurements from simulated tracks



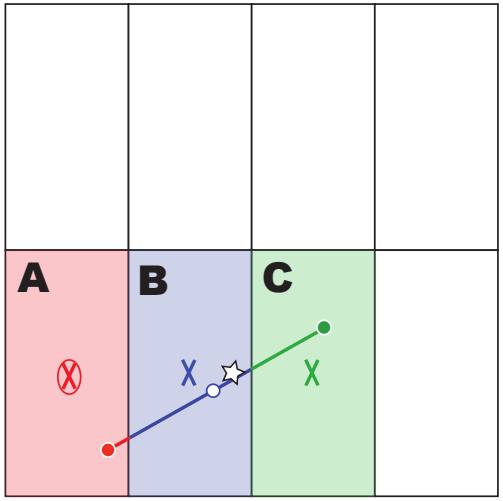
Add noise and merge clusters

Digitisation in fatras

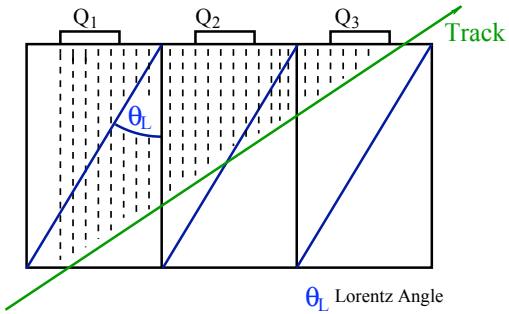
Silicon clusterisation with geometric approach



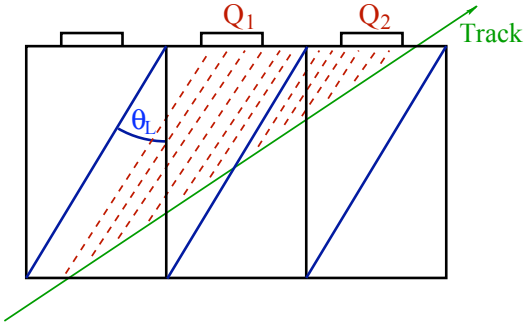
- intersection with surface
- exit of sensor material
- pixel position (vetoed)
- cluster position



Without Lorentz angle:



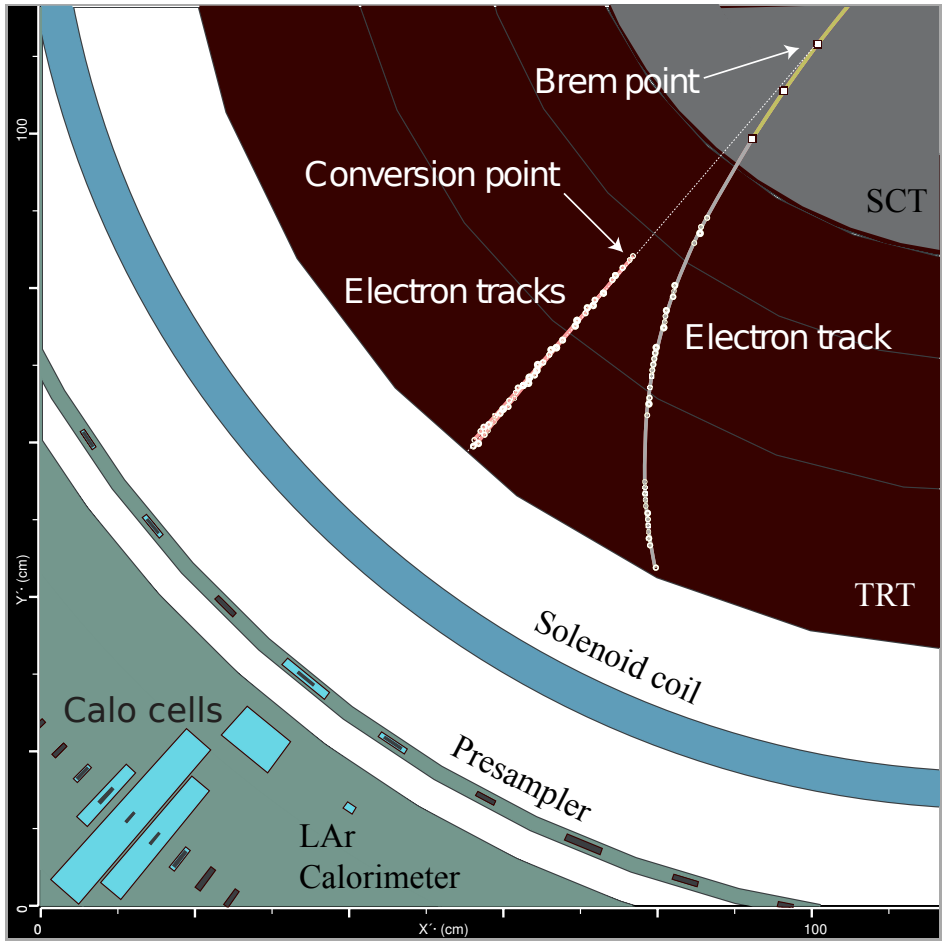
With Lorentz angle:



Combined Simulation

atlas and FastCaloSim

- atlas and FastCaloSim interfaced:



- atlas simulates the Inner Detector including secondaries
- Calorimeter deposits simulated by FastCaloSim
- Muon System simulated by atlas

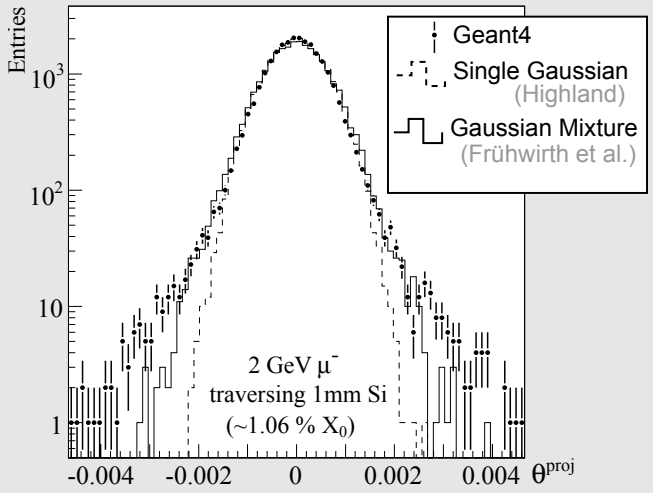
The Fast and the Furious

	Atlfast I	Atlfast II		Geant4/full
		Atlfast IIF	Atlfast II	
ID	parameterised track perigee	FatrasID	full simulation digitisation reconstruction	full simulation digitisation reconstruction
Calo	parameterised clusters	FastCaloSim	FastCaloSim muons: full	full/frozen G4 digitisation reconstruction
MS	parameterised track perigee's	Atlfast I FatrasMS	full simulation digitisation reconstruction	full simulation digitisation reconstruction
rel. gain	~ 1000	~ 100	~ 10	-

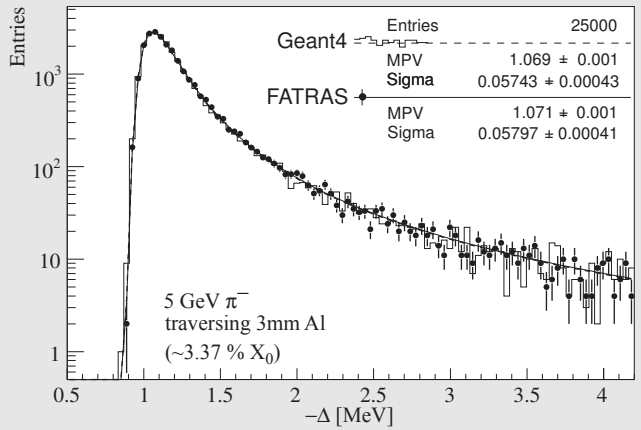
Material effects

Comparison of atlas and Geant4

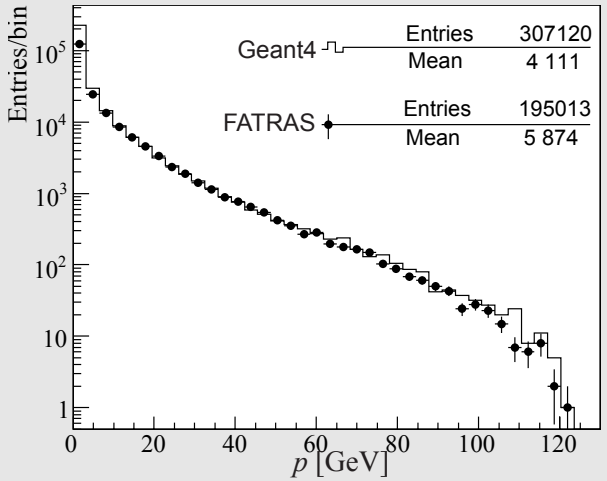
Multiple scattering



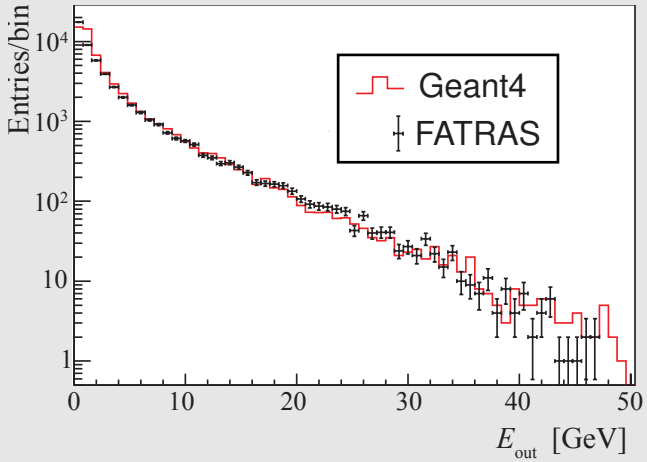
Energy loss



Radiation of brem photons

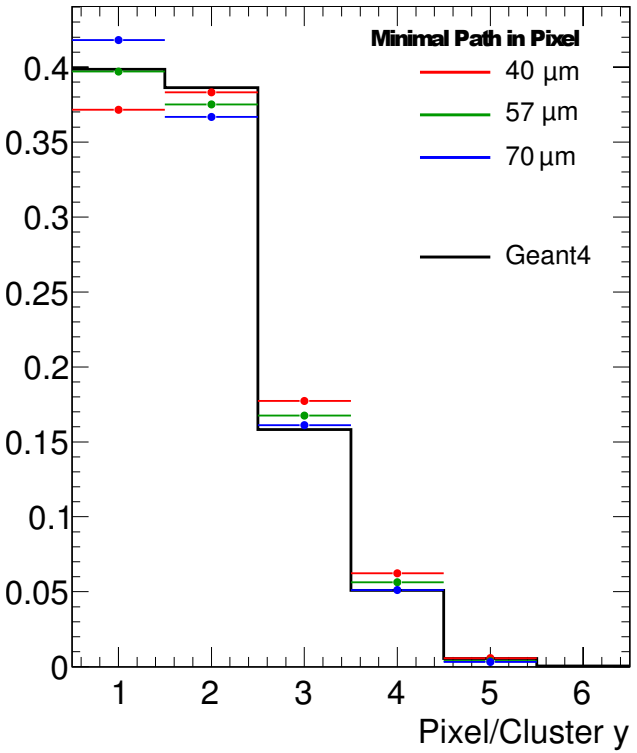


Hadronic interactions

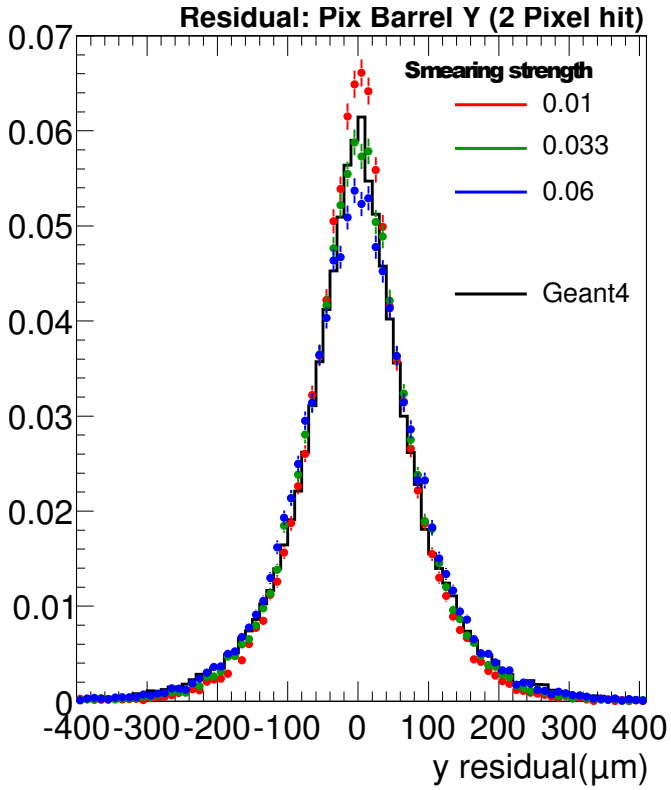


Digitisation in fatras
Tuning of the silicon clusterisation

- Pixels and SCT clusterisation tuned by adapting
  - minimal required path length in the Pixels cell
  - strength of Landau smearing
- Tuning can be done within 24h



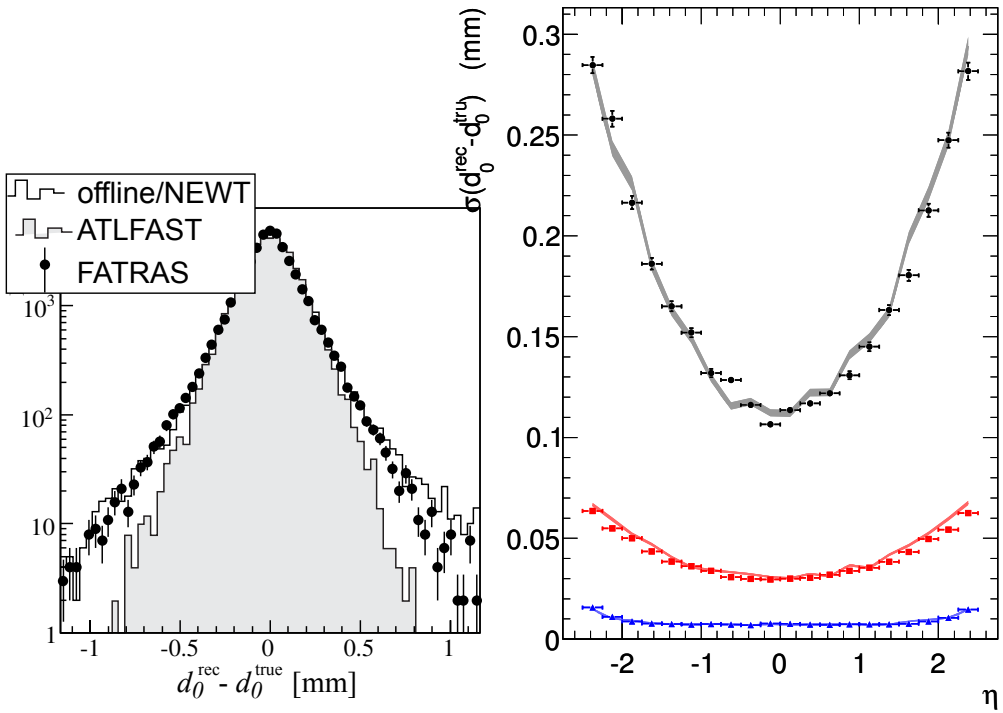
Cluster width in Pixels



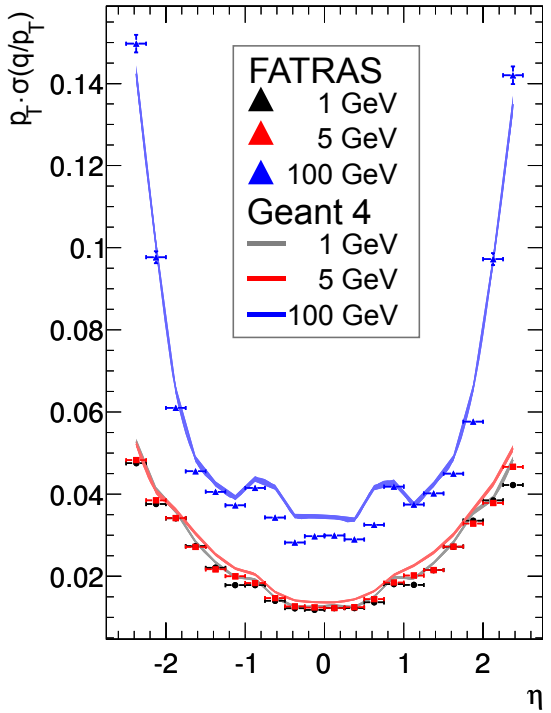
Measurement residual in Pixels

Track parameter resolutions

- Single muon events with p_T =1 GeV, 5 GeV, 100 GeV
- In general good agreement, but still some parameters to tune in the digitisation
- In particular tails better described than in ultra-fast sim



Transverse impact parameter d_0



Inverse track momentum q/p_T

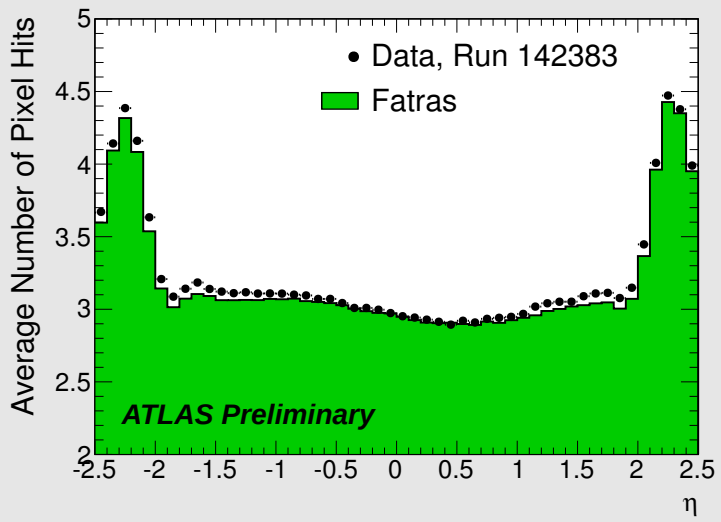
Reconstructed tracks in minimum bias events at $\sqrt{s} = 900$ GeV

- ATLAS on minimum bias Monte Carlo (Pythia) at the center of mass energy $\sqrt{s} = 900$ GeV
- Still some discrepancies, but ATLAS not yet tuned to data and misalignments of detector modules in data

Reconstructed tracks in minimum bias events

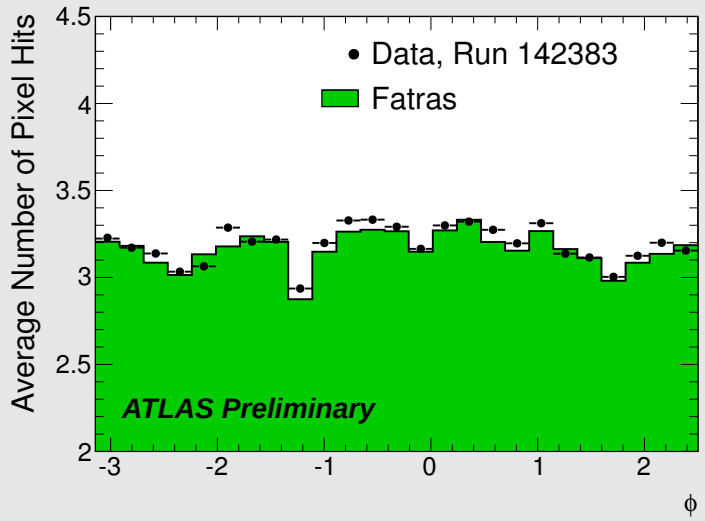
Average number of Pixels hits per track

Pixels hits / track vs η



"sinoidal structure" due to inactive Pixels modules in b-layer folded with the z-position of the primary vertex

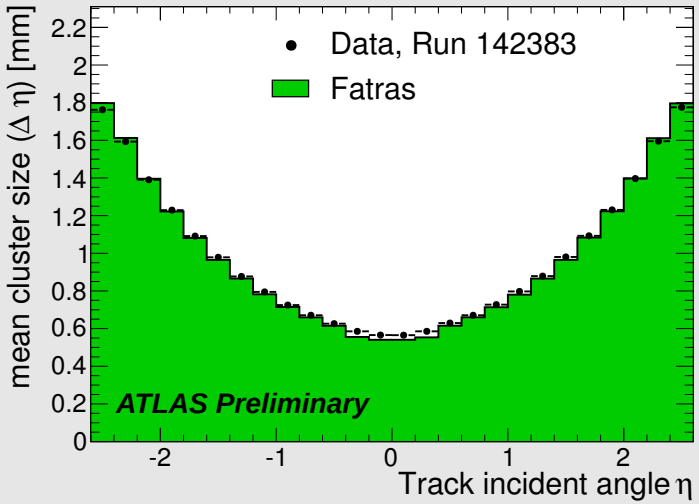
Pixels hits / track vs ϕ



- Detector conditions like inactive modules automatically taken into account in atlas
- Precise description of the detector geometry

Reconstructed tracks in minimum bias events at $\sqrt{s} = 900\text{GeV}$

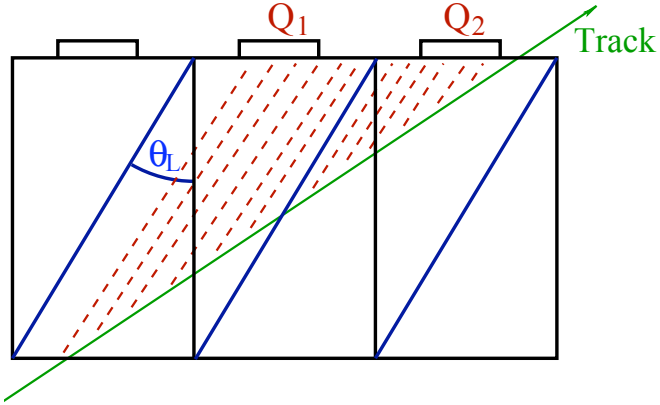
Pixel cluster size



Mean cluster size (in η direction) vs incident angle (η) on the Pixel module

- Cluster size depends on incident angle, because of sensor thickness

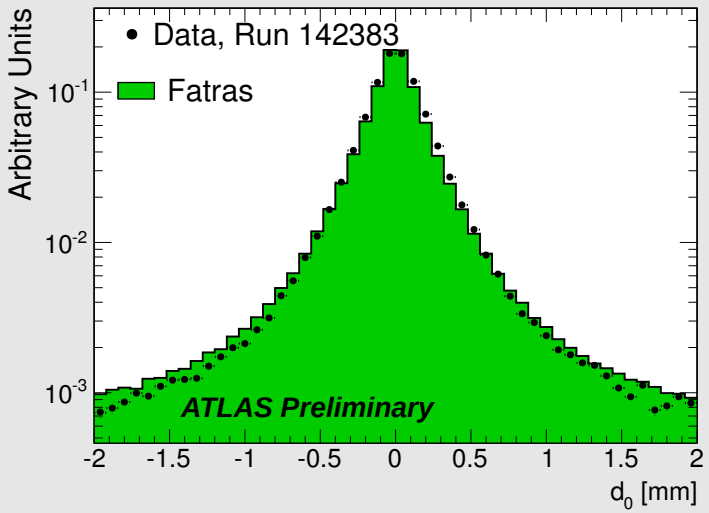
With Lorentz angle:



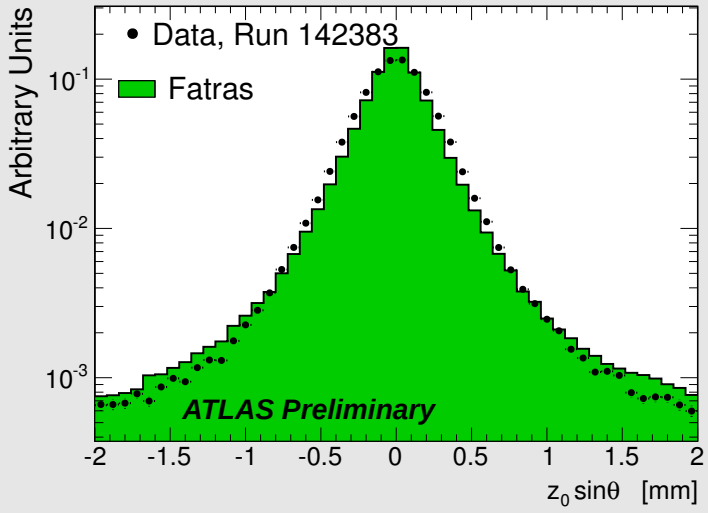
- Very sensitive test of the clusterisation model

Reconstructed tracks in minimum bias events at $\sqrt{s} = 900\text{GeV}$

Transverse impact parameter wrt. primary vertex



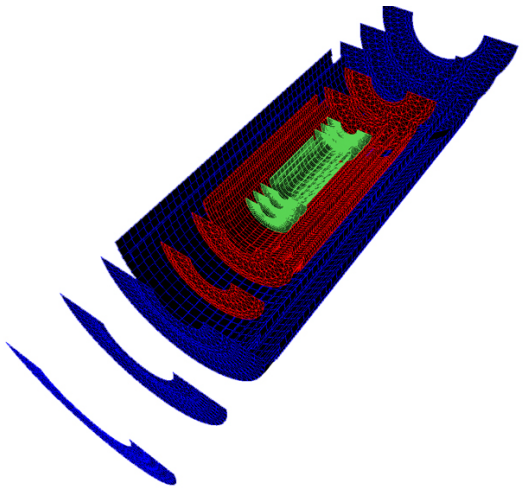
Longitudinal impact parameter

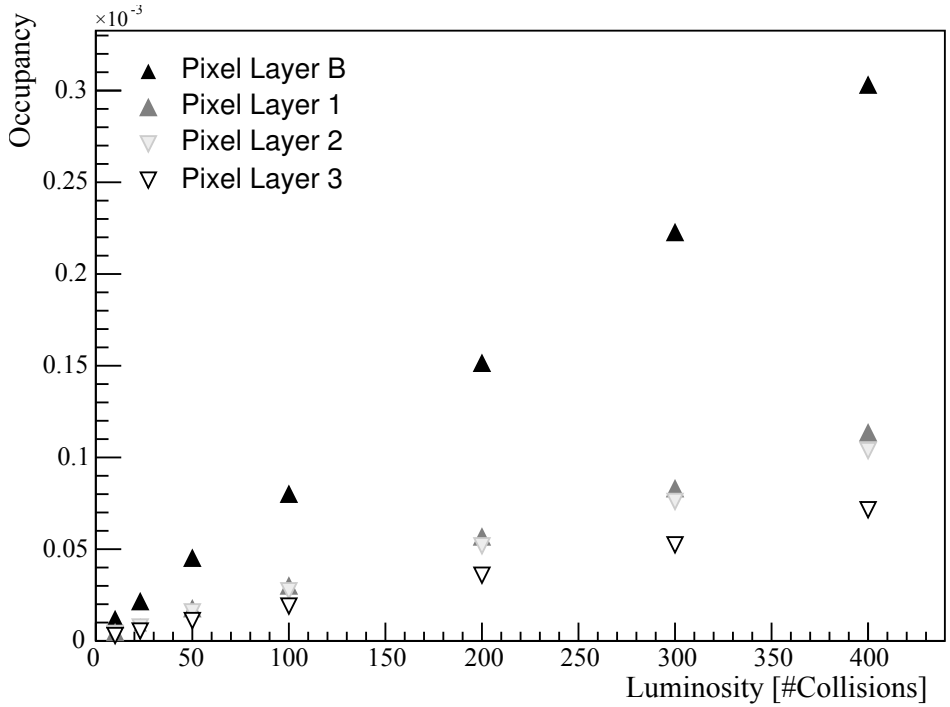


- Position and size of the beam spot in the simulation taken from detector conditions data base

fatras for Super-LHC upgrade studies

- fatras was used for SLHC upgrade studies of the ATLAS tracker
- Allows easy testing of various geometries at a reasonable time scale



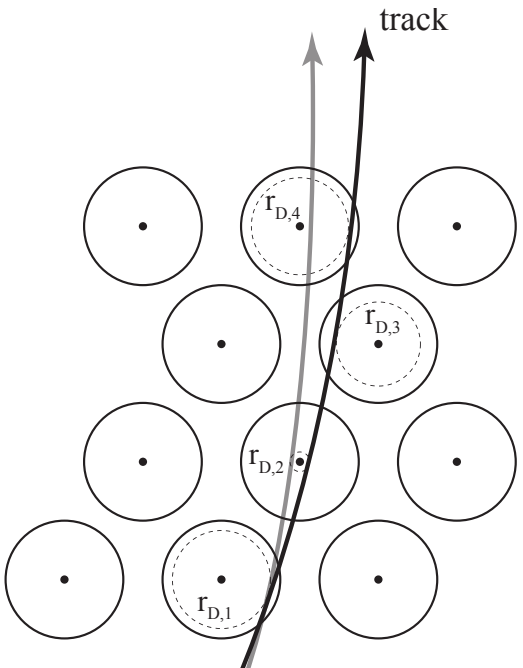


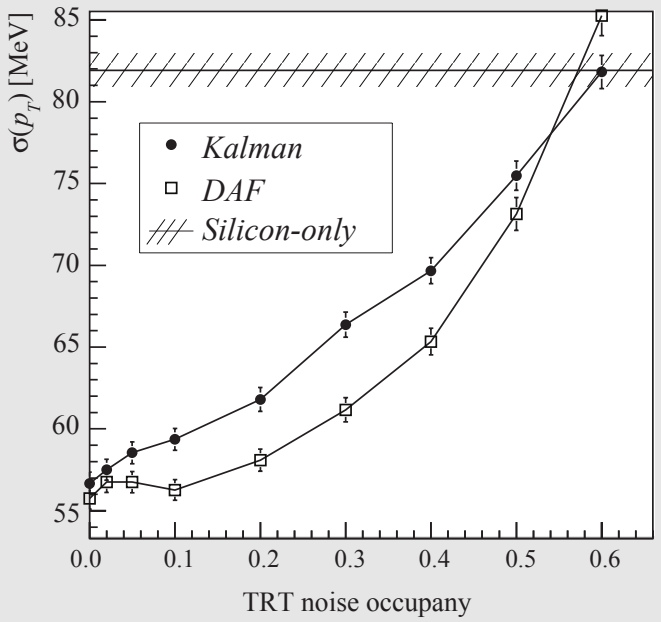
- Detector occupancies can be derived reliably
- Reconstruction effects are included in momentum resolutions, etc.

Stress tests for track fitters

simulation with high noise levels

- Detailed truth information by allows to evaluate performance of track fitters
- Quick simulation of arbitrary noise levels





5 GeV single muon events

- Example: Study of adaptive track fitter (Deterministic Annealing Filter)
- High detector occupancy
- Solution of left-right ambiguities in the TRT

Conclusions

- fatras is a new track simulation concept between full Geant4 simulation and conventional fast detector simulations
  - The full reconstruction chain can be run on fatras output
  - Speed improvement mostly due to simplified Tracking Geometry and extrapolation
  - (Nearly) no parametrisations needed
  - All important physics effects included, like multiple scattering, brem, conversions, particle decays, hadronic interactions
  - Allows studies to be performed that cannot easily be done either with full simulation or conventional fast simulations
- Currently in the tuning phase
- Validation with collision data has started

Acknowledgements

- Special thanks to Andreas Salzburger (CERN), Sharka Todorova (Tufts University) and Simone Zimmermann (Bonn)
- and

bcgs

Bonn-Cologne Graduate School of Physics and Astronomy

PHYSICS AT THE TERA SCALE

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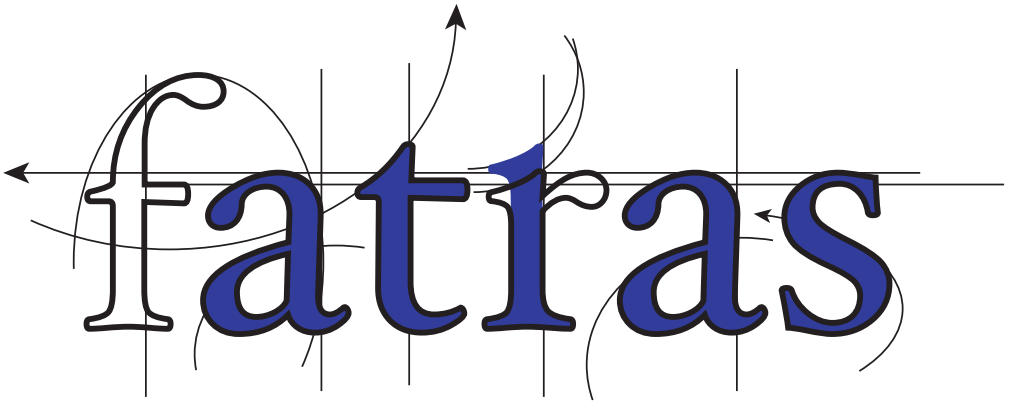
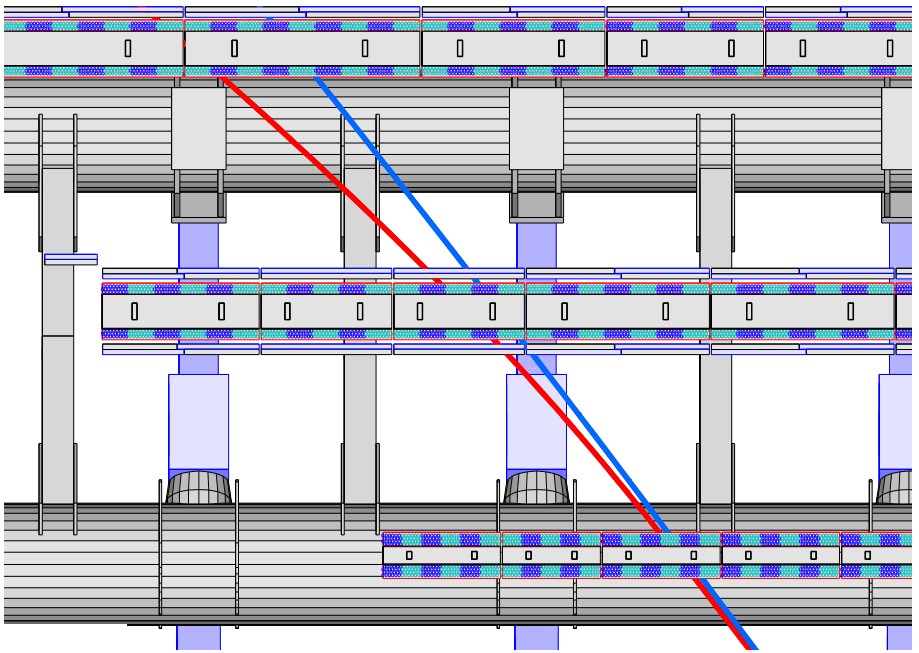


The ATLAS Muon System

- Monitored Drift Tubes (MDT)
  - $\approx$ 354k straw tubes
  - barrel and forward region
  - 80 μm straw resolution (Z)
  - 20 measurements / track
- Resistive Plate Chambers (RPC)
  - barrel region
  - chamber resolution: 10 mm (Z)/10 mm (ϕ)
  - 6 measurements / track
  - trigger (+ 2$^{\text{nd}}$ coordinate)
- Thin Gap Chambers (TGC)
  - end-cap
  - chamber resolution: $2-6$ mm (R)/$3-7$ mm (ϕ)
  - 9 measurements / track
  - trigger (+ 2$^{\text{nd}}$ coordinate)
- barrel toroid: $1.5-5.5$ Tm bending power, end-cap toroids: $1-7.5$ Tm
- Cathode-Strip Chambers (CSC)
  - forward region
  - multi-wire prop. chambers
  - plane resolution: 60μm (R)/5mm (ϕ)
  - 4 measurements / track



Muons with momenta of 4 GeV and 20 GeV in the bending plane of the barrel muon spectrometer.

– The green simulation

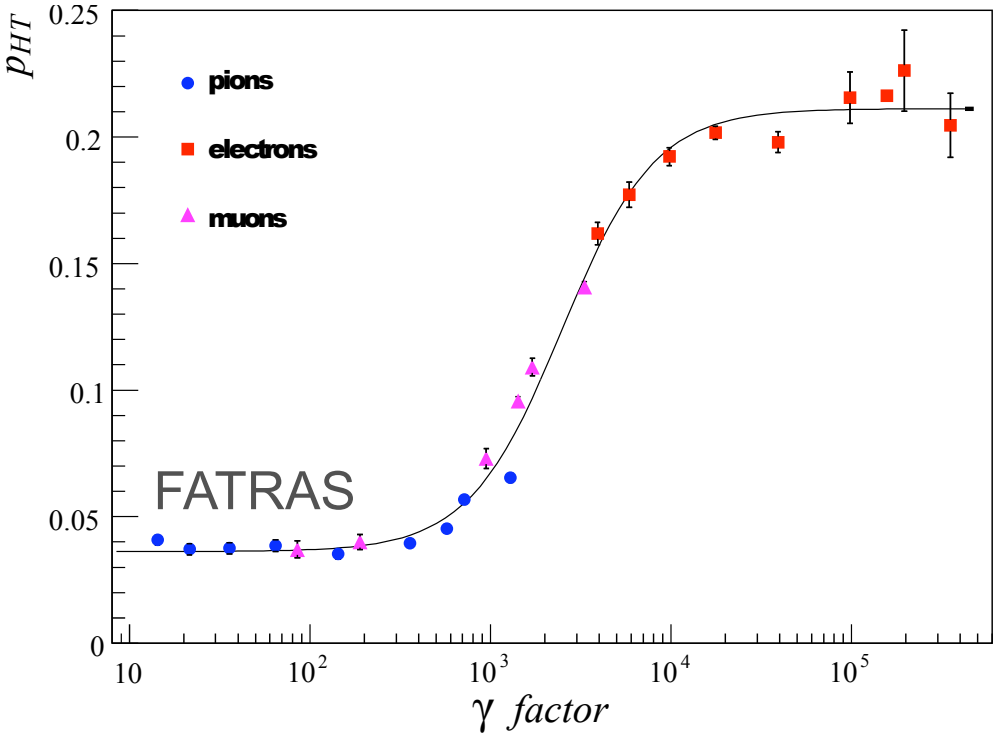
Simulation time/event, kSI2Kseconds	Minimum Bias	$t\bar{t}$	Jets	$W^{\pm} \rightarrow e^{\pm}\nu_e$	Heavy Ion
Full Sim	551	1990	2640	1150	56,000
Fast G4 Sim	246	757	832	447	21,700
ATLFAST-II	31.2	101	93.6	57.0	3050
ATLFAST-IIF	2.13	7.41	7.68	4.09	203
ATLFAST-I	0.029	0.097	0.084	0.050	6

- Hard to estimate how much CO_2 is emitted for one CPU second by the grid
- Taking 0.01 grams/s: Simulating 100k $t\bar{t}$ events with ATLFAST-IIF (+ `FastCaloSim`) instead of Full Simulation saves about 2 tons of CO_2

Digitisation in fatras

Simulation of hits with transition radiation in the Transition Radiation Tracker

- transition radiation in the TRT produces hits with stronger signal and is used for particle ID
- probability of transition radiation depends on relativistic γ factor
- measured with test beams and cosmic ray data
- fit of turn-on curve has been fed into fatras

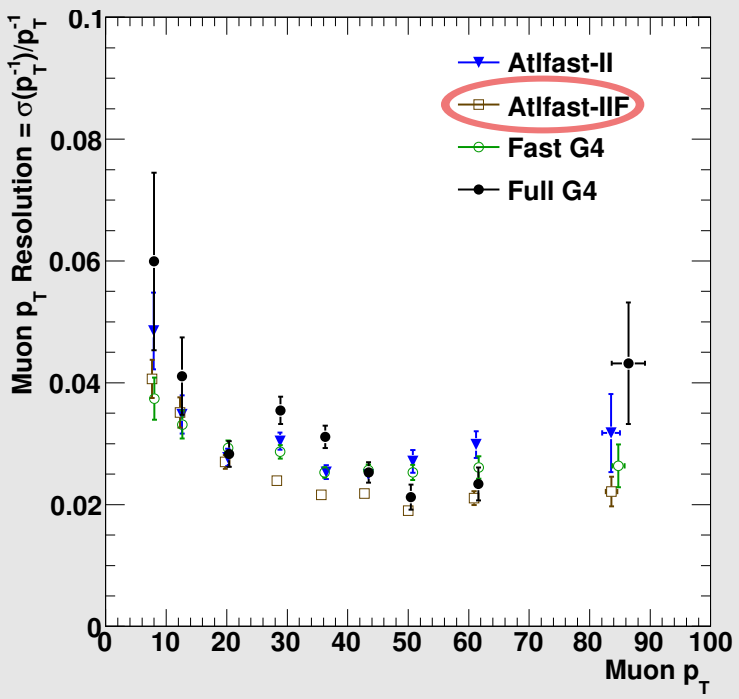


Combined simulation

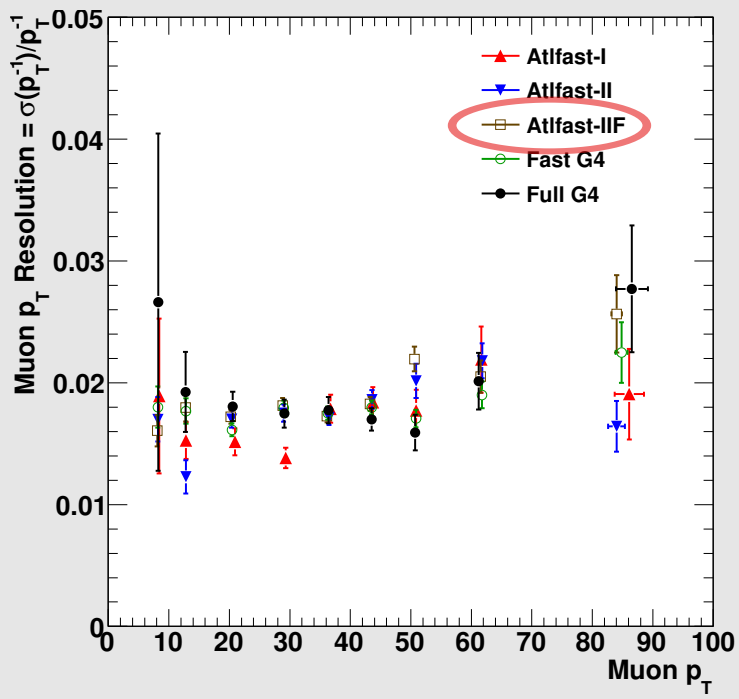
Comparison of reconstructed muon p_T resolution

- central muons ($|\eta| < 1.2$) in $Z \rightarrow \mu^+\mu^-$ events

Muon System stand-alone



Combined Muon Spectrometer / Inner Detector reconstruction



Reconstruction efficiencies

- Single electrons and muons with transverse momentum $p_T = 5$ GeV
- Shape roughly reproduced, but "too perfect" for electrons
  - Needs some extra fudge factors